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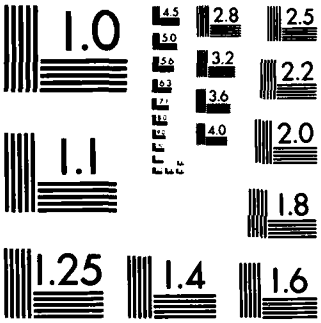

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March 1978

MASS AND POWER MODEL
FOR COMMUNICATIONS SPACECRAFT

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A Technical Report

Prepared for

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Systems Analysis Division
Resource Analysis Group
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Contract Number

N00014-77-C-0198

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PREFACE

This technical report is a complete rewrite of the previous working note WN-1064-USN of January 1977 which it supersedes. The data, estimating relationships and model have been completely updated and revised. Copies of the previous note are therefore obsolete and should be discarded or marked to avoid inadvertent use.

SUMMARY

The *Mass and Power Model for Communications Spacecraft* outlined in this technical report permits complete modelling of a spacecraft with only communications subsystem weight and power as input. It is designed for use early in the conceptual stage when very little information about the spacecraft has been determined other than operational requirements. Once the spacecraft has been modelled in mass and power, a cost model such as the *SAMSO Unmanned Spacecraft Cost Model* can be applied to obtain estimates of development and production costs.

For readers who do not require an in-depth understanding of how the relationships were derived, a brief overview can be obtained by reading Section II - DESCRIPTION OF THE MODEL and Section VI - APPLICATION OF THE MODEL. These two sections outline the results of the study and explain how the model is used.

I. INTRODUCTION

In December 1976, under contract N00014-73-0319/5, J. Watson Noah Associates, Inc. was tasked to prepare an independent cost analysis for a proposed Navy satellite. As the satellite was in the conceptual stage, there was very little information on which to base this estimate. A mass and power model[1] was developed that would estimate complete satellite weight and power by subsystem based only on communications subsystem weight and power. This permitted application of the SAMSO[2] cost model to various alternative configurations.

Despite successful application of the mass and power model, there was concern about the use of borrowed data, most of it undocumented. The data were also somewhat dated, since no new (1974 or later) satellites were represented. Effort commenced, under contract N00014-77-C-0198, to collect and document weight and power data on as many satellites as possible. Special emphasis was placed on newer, larger satellites. The original intention was to revise the existing model by the use of new, substantiated data. It soon turned out, however, that much better relationships could be obtained using the new data. As a result, the mass and power model has been completely revised. The result is a much improved mass and power model which supercedes in its entirety the older version.

The model is based on data from 14 actual spacecraft -- 9 spin-stabilized and 5 body-stabilized. It tests well against sample spacecraft of known parameters. The model should be useful on all proposed spacecraft of current state-of-the-art where communications subsystem weight and power can be established or estimated for input.

1/ *Mass and Power Model for Communications Spacecraft*, G.R. Kreisel, J. Watson Noah Associates, Inc., WN-1064A-USN, January 1977.

2/ *SAMSO Unmanned Spacecraft Cost Model*, Third Edition, C.J. Rohwer, et al, August 1975.

II. DESCRIPTION OF THE MODEL

A breakdown of spacecraft and launch vehicle subsystems for which mass and power relationships were developed is given in Table II-1, accompanied by brief definitions of the equipment included in each element.

Communications satellite mass and power relationships are given in Table II-2. Spin-stabilized and body-stabilized spacecraft formulas are listed in separate columns since the weight and power relationships vary for the two types. In both cases, weight of the communications subsystem is required as input. Normally, the power requirement for the communications subsystem would also be input to the model. Where end-of-life power requirement has already been estimated, this can be input directly, eliminating some of the intermediate steps.

Spacecraft dry weights (without Positioning & Orientation fuel), plotted in Figure II-1, indicate a cross-over point in the utility of these two types of spacecraft. Up to about 350 pounds of payload (communications and power supply) weight, the spin-stabilized configuration produces the lighter spacecraft in orbit. Above about 350 pounds, the body-stabilized spacecraft has an increasingly large advantage. This is, of course, based on prior and today's state-of-the-art and could be altered with changing technology.

The weight and length of the upper stage is obtained from Table II-3. There are only 3 vehicle configurations proposed for development and use as upper stages. Weight and length of the upper stage are very important since, in general, NASA launch charges will be based on the proportion of total spacecraft (plus upper stage) weight to shuttle load capability or spacecraft (plus upper stage) length to shuttle bay length, whichever is greater. In addition to the upper stage itself, a cradle (or adapter) and spin-platform must enter into the weight/length equation.

TABLE II-1

SPACECRAFT & LAUNCH VEHICLE SUBSYSTEMS

SPACECRAFT	
PAYLOAD	
COMMUNICATIONS	Antennas, transmitters, receivers, communications processors
POWER	Solar panels, batteries, regulation, wire harnesses
BUS	
STRUCTURE	Frame, supports, substrates, thermal control
TT&C	Telemetry, tracking and command for spacecraft & communications control
POSITIONING & ORIENTATION (DRY)	Attitude control electronics, reaction control system
POSITIONING & ORIENTATION FUEL	Fuel for stationkeeping and attitude control on orbit, velocity correction during injection
APOGEE MOTOR CASE	If required -- remains with spacecraft after burnout
APOGEE FUEL	Fuel for injection into synchronous orbit
ADAPTER	Adapter — spacecraft to upper stage
LAUNCH VEHICLE	
UPPER STAGE	For injection from 160nm parking orbit into synchronous transfer orbit
CRADLE/ADAPTER	Holds spacecraft & upper stage in shuttle bay. Includes integral spin platform for Spinning Solid Upper Stage (SSUS)

See Appendix for further definition of terms.

TABLE II-2

COMMUNICATION SATELLITE
WEIGHT AND POWER RELATIONSHIPS

COMPONENT 1/	SYMBOL	FORMULA 2/ SPIN-STABILIZED	FORMULA 2/ BODY-STABILIZED	REMARKS
WEIGHTS				
1. COMMUNICATIONS	W_C	Input	Input	
2. POWER SUPPLY	W_{PS}	$.42\ P_{BOL}$ (7)	$3.16T^{-.82}\ P_{BOL}$ (8)	T=Technological age (years since 1958)
3. PAYLOAD	W_{PY}	$W_C + W_{PS}$	$W_C + W_{PS}$	
4. BUS (DRY, W/O AKM)	W_{BX}	$1.06\ W_{PY}$ (10)	$164 + .43\ W_{PY}$ (9)	
5. SPACECRAFT (DRY, W/O AKM)	W_{SX}	$W_{BX} + W_{PY}$	$W_{BX} + W_{PY}$	
6. STRUCTURE	W_{ST}	$.64\ W_{BX}$ (11)	$.60\ W_{BX}$ (12)	
7. TT&C	W_{TC}	$.11\ W_{BX}$ (13)	$.10\ W_{BX}$ (14)	
8. P&O (DRY)	W_{PO}	$.25\ W_{BX}$ (15)	$.30\ W_{BX}$ (16)	
9. AKM CASE	W_{AM}	$12 + .20\ W_{BX}$ (17)	$12 + .20\ W_{BX}$ (17)	If used
10. BUS (DRY)	W_{BD}	$W_{BX} + W_{AM}$	$W_{BX} + W_{AM}$	
11. SPACECRAFT (DRY)	W_{SD}	$W_{BD} + W_{PY}$	$W_{BD} + W_{PY}$	
12. P&O (FUEL)	W_{PF}	$.031\ W_{SD}\ Y$ (18)	$.029\ W_{SD}\ Y$ (19)	
13. BUS (WET)	W_{BW}	$W_{BD} + W_{PF}$	$W_{BD} + W_{PF}$	
14. SPACECRAFT (WET)	W_{SW}	$W_{BW} + W_{PY}$	$W_{BW} + W_{PY}$	
15. APOGEE FUEL	W_{AF}	$.97\ W_{SW}$ (20)	$.97\ W_{SW}$ (20)	
16. SPACECRAFT (SEPARATION)	W_{SS}	$= W_{SW} + W_{AF}$	$W_{SW} + W_{AF}$	
17. ADAPTER	W_{AA}	62 (21)	62 (21)	
18. UPPER STAGE	W_{US}			See Table II-3
19. CRADLE/ADAPTER	W_{CR}			See Table II-3
20. SHUTTLE LOAD	W_L	$W_{SS}+W_{AA}+W_{US}+W_{CR}$	$W_{SS}+W_{AA}+W_{US}+W_{CR}$	
POWER				
1. COMMUNICATIONS	P_C	Input	Input	$P_C = .79\ P_{EOL}$ (1)
2. END-OF-LIFE	P_{EOL}	$1/.79\ P_C$ (4)	$1/.79\ P_C$ (4)	
3. POWER SUPPLY	P_{PS}	$.06\ P_{EOL}$ (2)	$.06\ P_{EOL}$ (2)	
4. SATELLITE PAYLOAD	P_{PY}	$P_C + P_{PS}$	$P_C + P_{PS}$	
5. BUS	P_B	$.15\ P_{EOL}$ (3)	$.15\ P_{EOL}$ (3)	
6. BEGINNING-OF-LIFE	P_{BOL}	$(1+.044Y)\ P_{EOL}$ (5)	$(1+.059Y)\ P_{EOL}$ (6)	Y = design life, years.

1/ See Table II-1 and Appendix for definitions

2/ Parenthetical numbers refer to derivations in text

FIGURE II-1. SPACECRAFT WEIGHT - DRY (W/O POSITION. & ORIENT. FUEL)

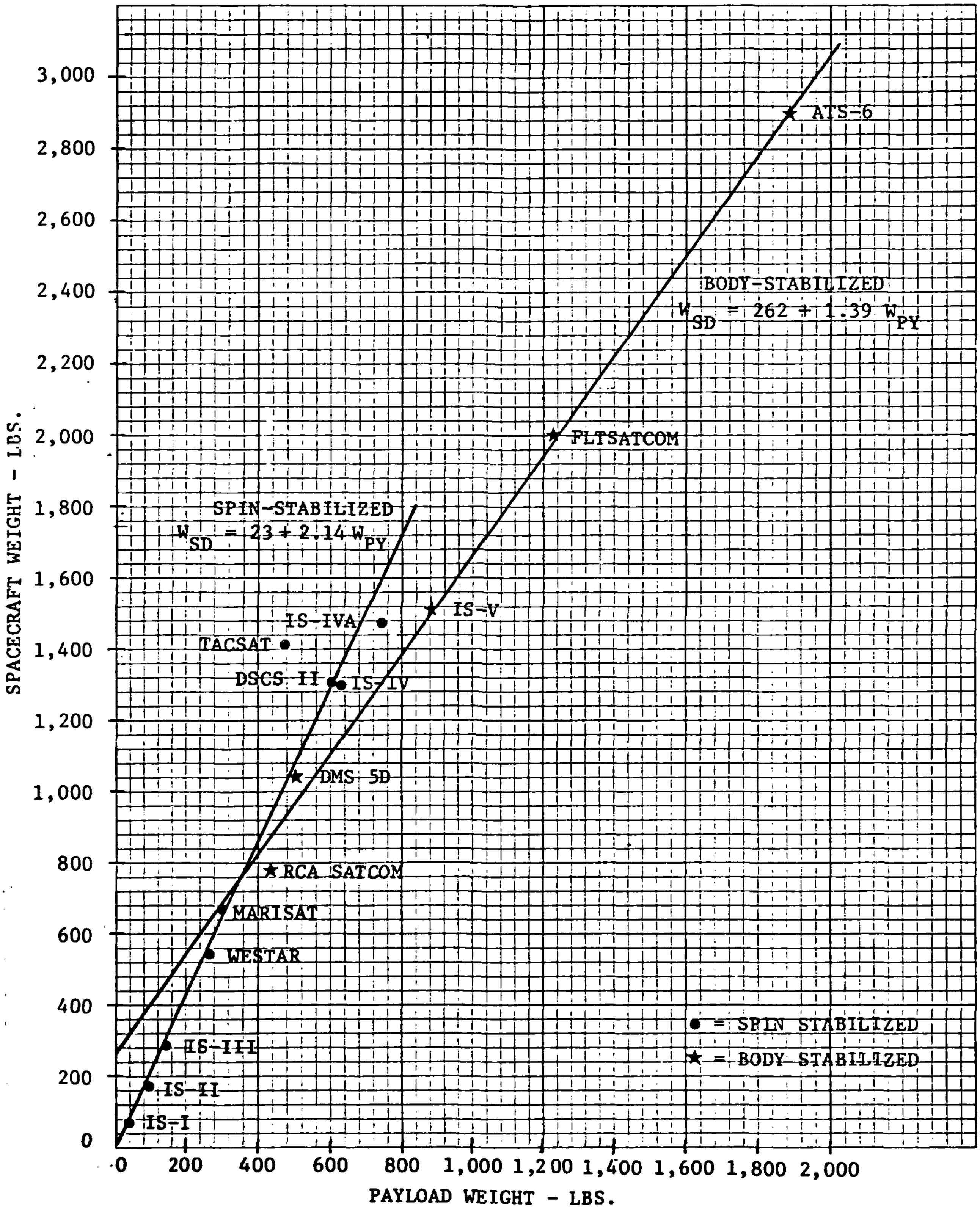


TABLE II-3

UPPER STAGE REQUIREMENTS OF SYNCHRONOUS ORBIT SPACECRAFT

(SPACE SHUTTLE LAUNCH TO 160NM PARKING ORBIT)

WEIGHT OF SATELLITE		UPPER STAGE							
			WEIGHT (LBS)			LENGTH (FT)			
INITIAL IN-ORBIT WEIGHT LBS	TRANSFER ORBIT WEIGHT LBS	TYPE	UPPER STAGE	CRADLE/ ADAPTER	TOTAL	UPPER STAGE	CRADLE/ ADAPTER	TOTAL	REMARKS
up to 1300	up to 2500	SSUS-D (Delta Class)				6.4	3	9.4	Spin-Stabilized injection to synchrono transfer orbit. Up 4 in shuttle bay.
1300 to 2350	2500 to 4500	SSUS-A (Atlas Centaur Class)	8,000	3,000	11,000	8.2	3	11.2	Spin-Stabilized injection to synchrono transfer orbit. 2 i shuttle bay.
up to 5000	N/A	IUS (AF)	32,000	3,700	35,700	14.9	-	14.9	Direct injection to synchronous orbit. axis stabilized. Multiple launch possible. Offloading propellent permits 2 IUS's in tandem in shuttle bay.

III. POWER RELATIONSHIPS

A. End-of-Life Power Prediction

One of the objectives of this mass and power model is to be able to predict total satellite power requirement early in the conceptual phase when only communications power is known with any degree of certainty. Data on communications (or experimental package) power for six satellites were obtained and summarized in Table III-1. There is insufficient data to make any attempt to separate the two spin-stabilized and the four body stabilized spacecraft, so they are combined into a single data base.

The end-of-life power is plotted against communications power in Figure III-1. A regression yields the following results:

$$P_{EOL} = 82 + 1.139\ P_C$$

where,

P_{EOL} = End-of-life power - watts

P_C = Communications subsystem power - watts

and

Standard Error of the Estimate (SE_{EST}) = 102

R^2 = .94

The relationship is a good one based on these statistics. However, the significance of the constant (intercept) is statistically poor since its Standard Error is 80 and its T-score is 1.019. A glance at the plot of Figure III-1 does nothing to indicate that the curve should not pass through the origin, either. A rerun of the regression through the origin yields the following:

$$P_{EOL} = 1.253\ P_C$$

where,

SE_{EST} = 102

TABLE III-1

SATELLITE SUBSYSTEM POWER REQUIREMENTS

POWER REQUIREMENTS	SYMBOL	FLTSATCOM	MARISAT	DSCS II	RCA SATCOM	ATS-6	INTELSAT V BUDGET 4/
COMMUNICATIONS (EXPER.)	P_C	1,072	223	273	435	334 1/	856
POWER (INCL. HARNESS)	P_{PS}	32	2	34	19	52	118
PAYLOAD	P_{PY}	1,104	225	307	454	386	974
BUS	P_B	109	73	51	59	168	217
E.O.L. POWER	P_{EOL}	1,210	305	358	513	554	1,191
SOLAR ARRAY							
EOL		1,210	305	358	550	450 2/	1,191
BOL		1,574	-	535	770	645	-
DESIGN LIFE		5	5	5	8	2-5 3/	7

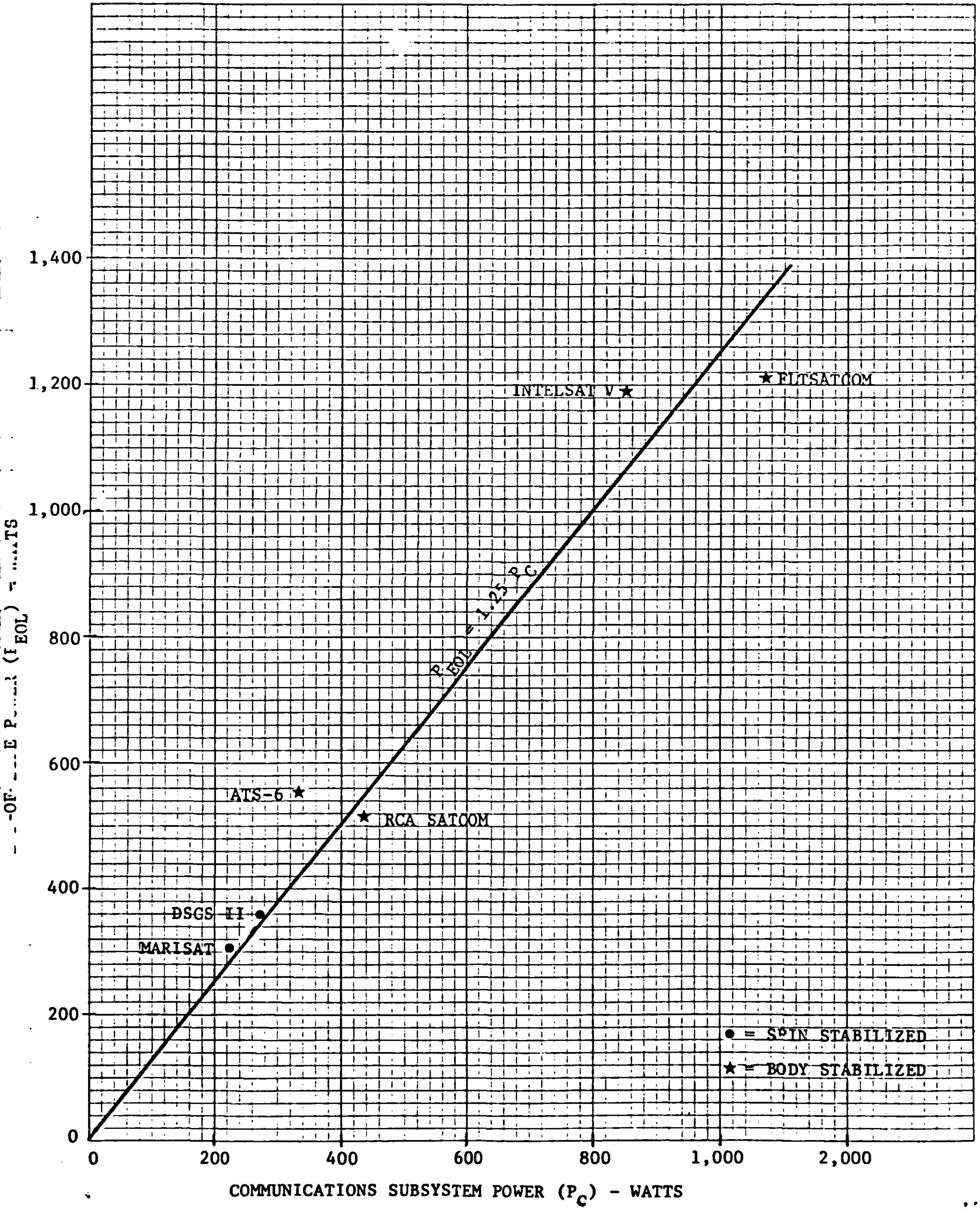
1/ Experiments do not operate continuously, but within power system capacity.

2/ 550 @ 1 yr.; 510 @ 2 yrs.; 450 @ 5 yrs.

3/ Nominally 2 years. Reduced capability expected for 5 years.

4/ 56 watts spacecraft margin pro-rated to subsystems.

FIGURE III-1. END-OF-LIFE POWER



B. Subsystem Power

Breakdown of power into subsystems may be useful in application of some cost models. Table III-1 includes information on power subsystem and spacecraft bus as well as communications power requirements. Below this level, the data are rather sketchy. The data are plotted in Figures III-2, III-3, and III-4.

1. Power Subsystem Power: A regression yields the following:

$$P_{PS} = -1.7 + .0647\, P_{EOL}$$

where,

$$P_{PS} = \text{Power Subsystem Power - watts}$$

and,

$$SE_{EST} = 34$$

$$R^2 = .28$$

There is obviously a great deal of scatter in the data. This may be as much a result of definitional differences in assigning power to subsystems as to actual variations. The intercept is clearly not significant so the regression was rerun to yield:

$$P_{PS} = .0628\, P_{EOL}$$

where,

$$SE_{EST} = 31$$

2. Bus Power: The result of the regression is as follows:

$$P_B = 40 + .106\, P_{EOL}$$

where,

$$P_B = \text{Bus Power - watts}$$

FIGURE III-2. POWER SUPPLY POWER

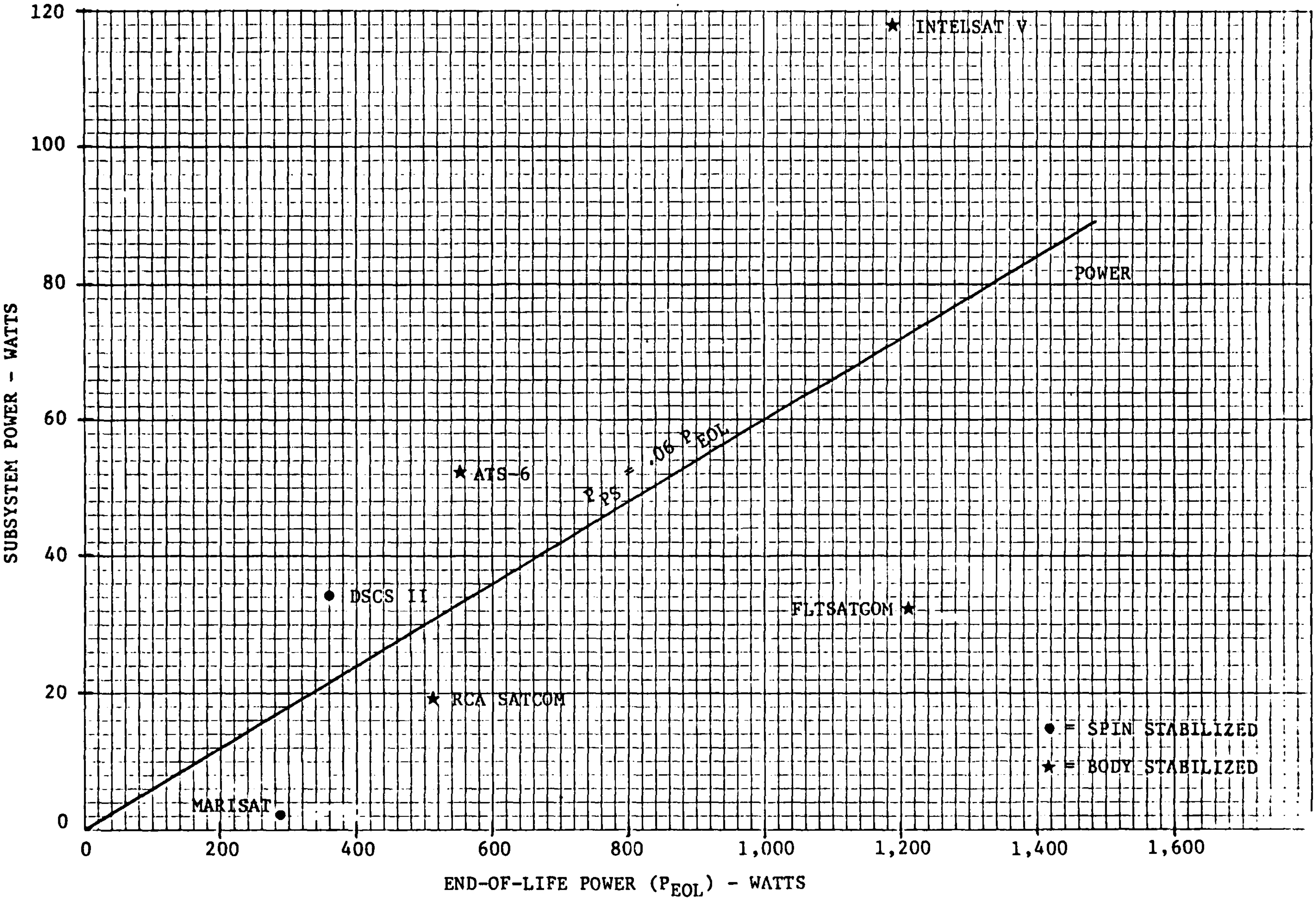


FIGURE III-3. SPACECRAFT BUS POWER

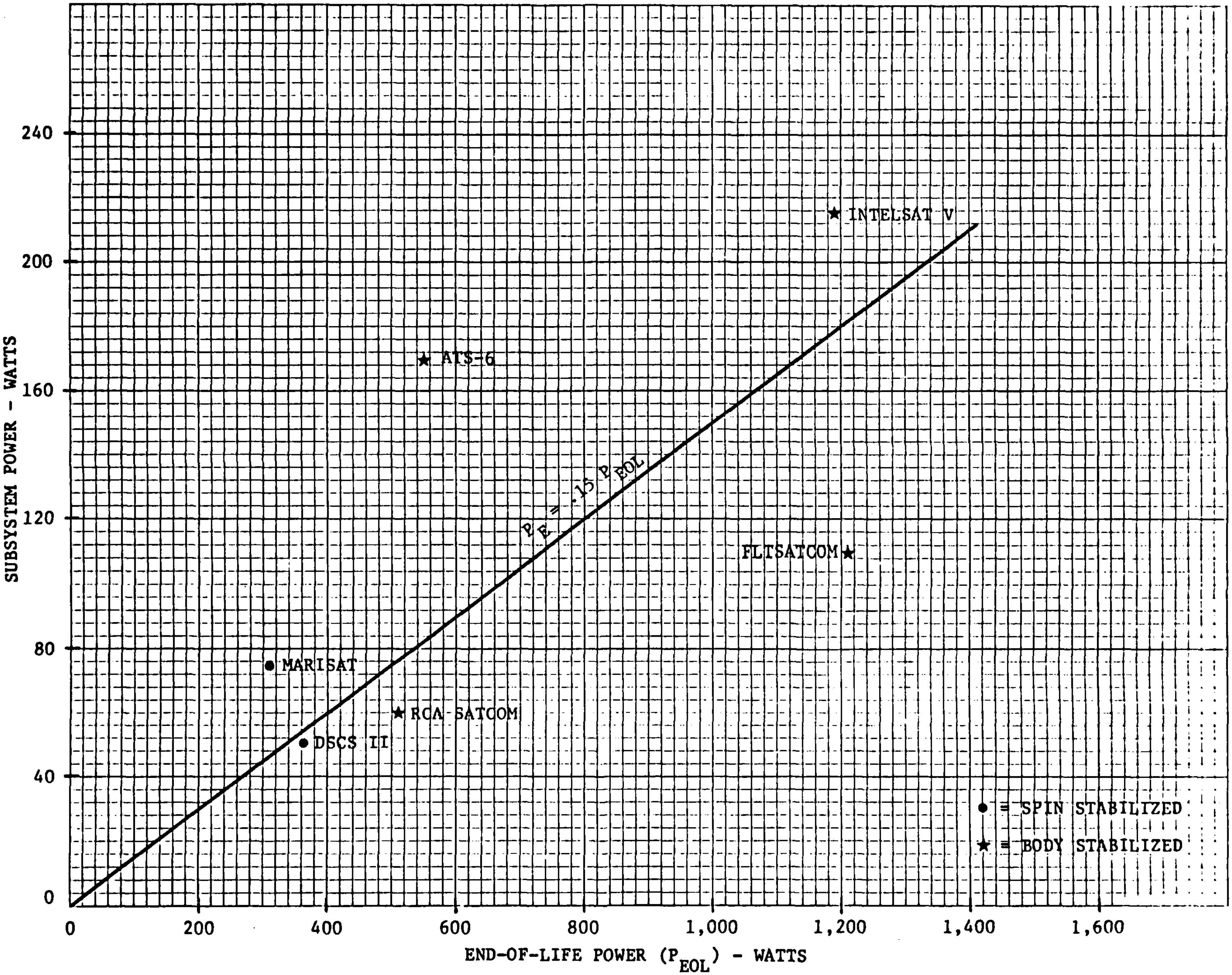
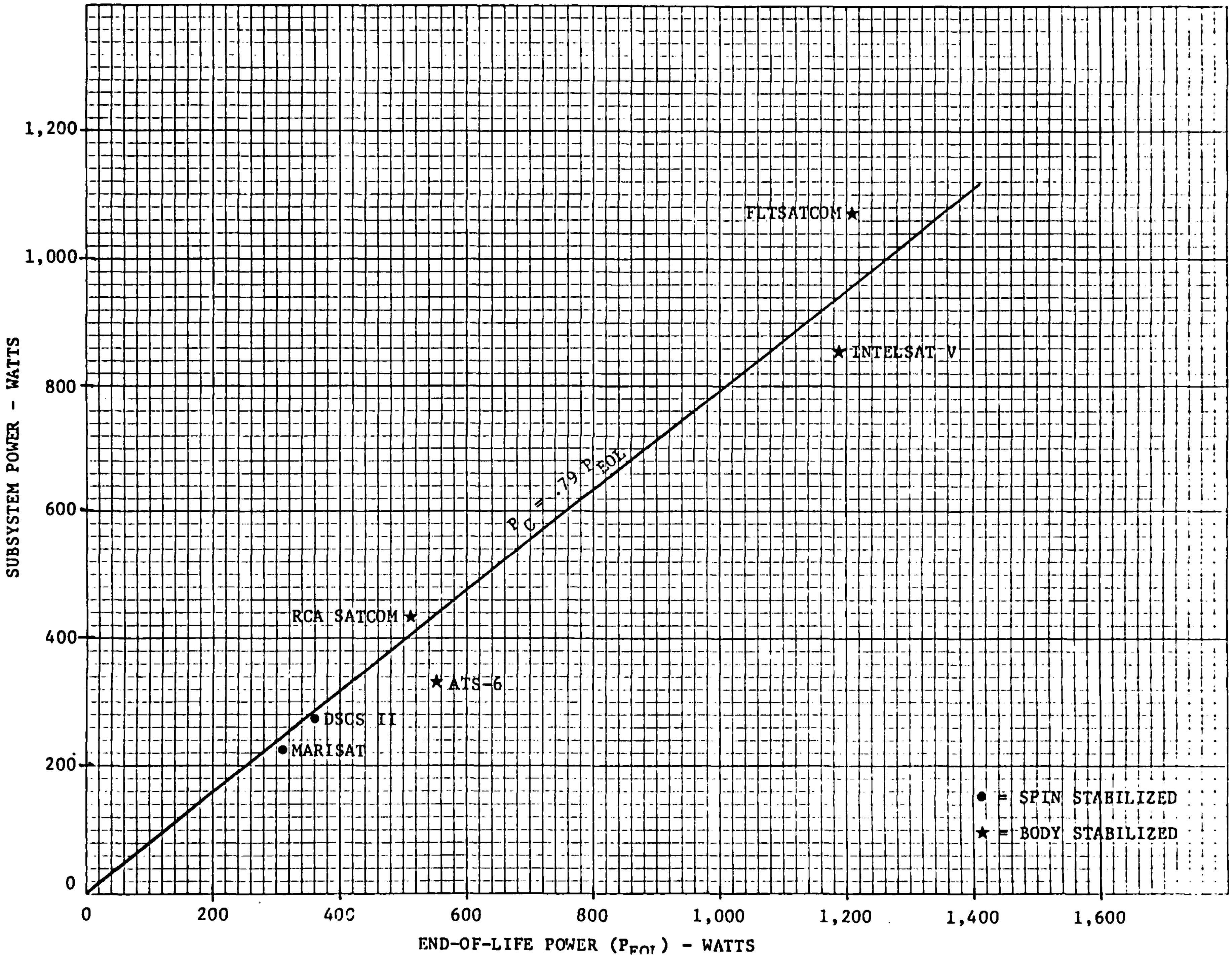


FIGURE III-4. COMMUNICATIONS POWER



and,

$$SE_{EST} = 57$$
$$R^2 = .28$$

Although there could easily be a 40 watt minimum power requirement for the spacecraft bus, an examination of Figure III-3 is not very convincing. The statistics aren't either, since the standard error of the constant is 49 and T-score only .82. A rerun of the regression yields:

$$P_B = .151\ P_{EOL}$$

where,

$$SE_{EST} = 55$$

3. <u>Communications Power</u>: A regression of communications power vs. end-of-life power was also run to close the loop — this being essentially the reverse of the initial effort to predict end-of-life power from communications power.

$$P_C = -42 + .834\ P_{EOL}$$

where,

$$SE_{EST} = 87$$
$$R^2 = .94$$

Again, the constant term was not significant -- having a standard error of 75 and T-score of -.6. Without the constant, the relationship becomes:

$$P_C = .787\ P_{EOL}$$

where

$$SE_{EST} = 81$$

The inverse of the relationship is

$$P_{EOL} = 1.271\ P_C$$

which very closely matches the results in Section IIIA.

4. Total of Subsystem Powers: The total power for the subsystems must equal 100% of the end-of-life power. Only a slight adjustment is necessary, and rounding is done to simplify the relationships:

$$P_C = .79\ P_{EOL} \qquad (1)$$

$$P_{PS} = .06\ P_{EOL} \qquad (2)$$

$$P_B = .15\ P_{EOL} \qquad (3)$$

In order to assure that all the power relationships are fully compatible and all spacecraft power is accounted for, the inverse of relation (1) will be used to determine end-of-life power in this model.

$$P_{EOL} = P_C/.79 \qquad (4)$$

C. Beginning-of-Life Power

Power requirements of spacecraft are usually expressed in end-of-life power which is the minimum power required to keep the spacecraft in operation at the end of its design life. Beginning-of-life solar array power must be considerably higher to account for deterioration of the solar cells due to radiation effects in outer space. The longer the design life, the greater the disparity between beginning-of-life and end-of-life power. The power supply and the supporting spacecraft bus must be designed for the beginning-of-life requirement. By basing subsystem weight relationships on beginning-of-life power, a large portion of the effects of design lifetime on spacecraft weight (and cost) can be taken into account.

Beginning-of-life and end-of-life power requirements for all spacecraft where both specifications were available were tabulated in Table III-2. The ratio of the two numbers was determined in order to plot the results against design life in Figure III-5. Regressions were run on the data, separated into body-stabilized and spin-stabilized spacecraft. The difference between types of spacecraft occurs because body-stabilized solar panels remain oriented toward the sun, causing more rapid deterioration. Spin-stabilized solar panels are exposed only part of the time, reducing both heat and radiation, and consequently they retain power longer. In both cases, the curves were constrained to pass through the origin (Ratio = 1.0 for a design life of 0 years).

SPIN-STABILIZED SPACECRAFT

$$P_{BOL}/P_{EOL} = 1.0 + .044Y$$

where,

P_{BOL} = Beginning-of-Life Power - watts

P_{EOL} = End-of-Life Power - watts

Y = Design Life - years

and,

SE_{EST} = .009

BODY-STABILIZED SPACECRAFT

$$P_{BOL}/P_{EOL} = 1.0 + .059Y$$

where,

SE_{EST} = .006

The data are widely scattered and the resultant regression statistics do not lend much support to the hypotheses. Based on understanding of the underlying principles (and study of the plot of Figure III-5) the relationships appear reasonable and consistent. The relationships will be used in

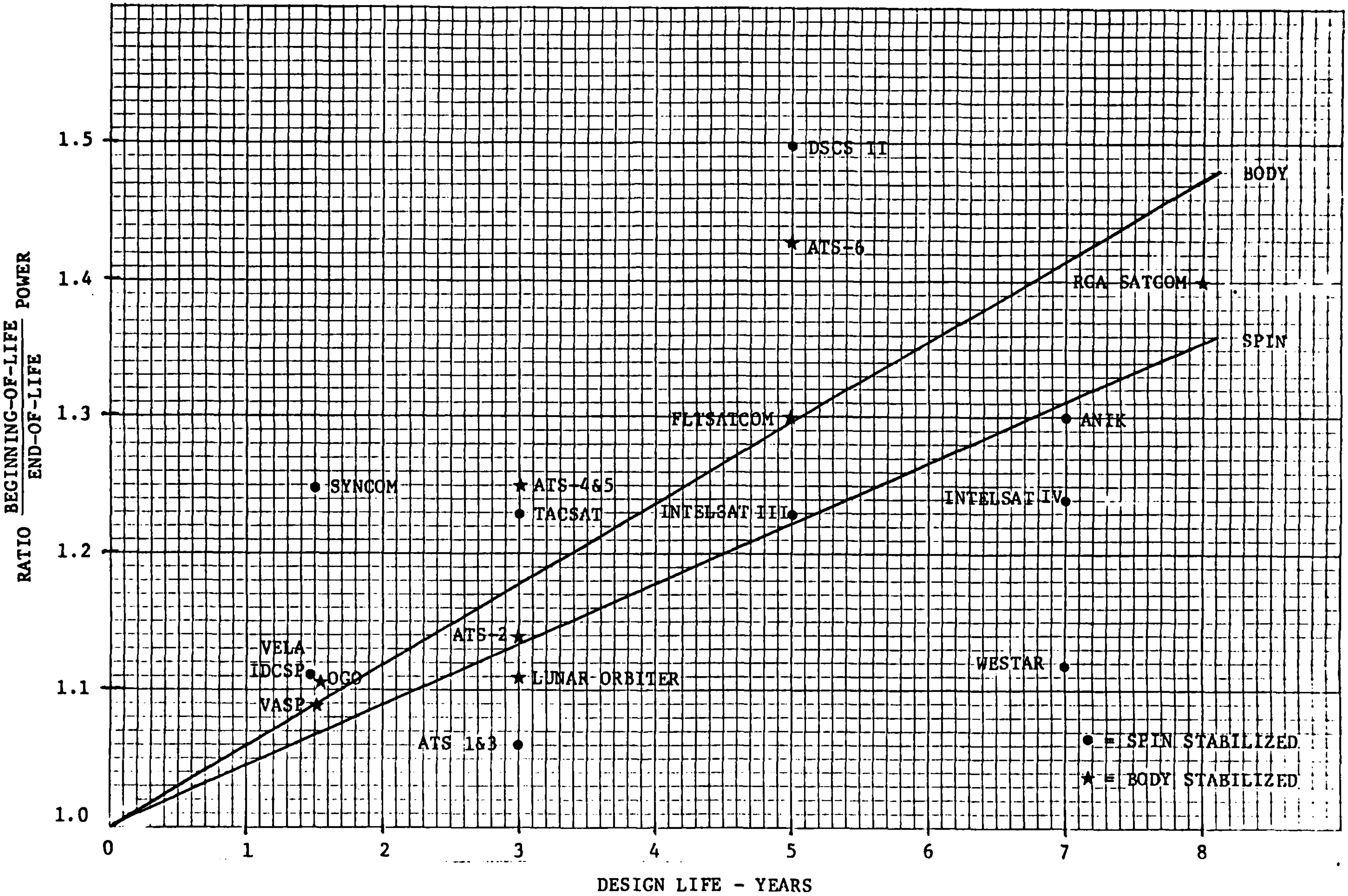
TABLE III-2

COMMUNICATIONS SATELLITE POWER REQUIREMENTS

SATELLITE	DESIGN LIFE (YEARS)	BEGINNING-OF-LIFE POWER (WATTS)	END-OF-LIFE POWER (WATTS)	RATIO P_{BOL}/P_{EOL}
SPIN-STABILIZED				
TACSAT	3	960	780	1.23
ATS-1&3	3	180	170	1.06
INTELSAT III	5	161	131	1.23
INTELSAT IV	7	569	460	1.24
SYNCOM	1.5	25	20	1.25
DSCS II	5	535	357	1.50
VELA	1.5	105	95	1.11
IDCSP	1.5	40	36	1.11
WESTAR[1/]	7	241	216	1.12
ANIK[1/]	7	300	230	1.30
BODY STABILIZED				
ATS-2	3	125	110	1.14
ATS-4&5	3	140	112	1.25
ATS-6	5	645	450	1.43
VASP	1.5	120	110	1.09
OGO	1.5	500	450	1.11
LUNAR ORBITER	3	400	360	1.11
FLTSATCOM	5	1574	1210	1.30
RCA SATCOM	8	770	550	1.40

[1/] Although essentially the same satellite, power data obtained from different sources show considerable variation.

FIGURE III-5. BEGINNING-OF-LIFE TO END-OF-LIFE POWER RATIO



the model even though the statistical support is not strong. Rearranging:

SPIN-STABILIZED

$$P_{BOL} = (1.0 + .044Y)\, P_{EOL} \tag{5}$$

BODY-STABILIZED

$$P_{BOL} = (1.0 + .059Y)\, P_{EOL} \tag{6}$$

IV. WEIGHT RELATIONSHIPS

The weight relationships derived for this Mass and Power Model are based primarily on complete weight summaries obtained on 14 spacecraft. Nine spin-stabilized and five body-stabilized spacecraft are represented in the sample. These summaries are given in Table IV-1.

A. Power Subsystems

Other than the communications subsystem weight which must be input to the model, the power subsystem weight is the most important. The power subsystem is designed to support the communications and other bus loads over the design lifetime of the spacecraft. The bus must be sized to support the weight of the communications and power subsystems, the payload, and errors in estimating power subsystem weight will be magnified in arriving at a final weight and power estimate.

Weights of power subsystems for satellites are compiled in Table IV-2. Where beginning-of-life array power is not available, it is computed from the factors derived in Section IIIC. Using beginning-of-life power will take into account much of the increased weight of the spacecraft resulting from longer design lifetimes. Power subsystem weights are then plotted against beginning-of-life power in Figure IV-1, separated into spin-stabilized and body-stabilized spacecraft. The weights are all inclusive weights of the power subsystems, including wire harnesses and dedicated solar panels for battery charging.

Regressions were performed on the data to fit the curves of Table IV-2. In both cases the intercepts were not very significant statistically, and examination of the graph indicated the curves should probably pass through the origin. The regressions were rerun to do this. Statistics for the regressions follow:

TABLE IV-1

SPACECRAFT WEIGHT SUMMARY
(WEIGHTS IN LBS.)

	SPIN-STABILIZED									BODY-STABILIZED				
SUBSYSTEM	TACSAT	INTELSAT I	INTELSAT II	INTELSAT III	INTELSAT IV	INTELSAT IV-A	DSCS II	MARISAT	WESTAR	ATS-6	FLTSATCOM	RCA SATCOM 4/	DMS 5D	INTELSAT V 7/
COMMUNICATIONS 1/	183	18	42	59 3/	336	406	254	157	121	998	490	227	320	503
POWER SUPPLY 2/	290	17	51	80	291	334	347	144	140	890	740	208	177	384
PAYLOAD	473	35	93	139	627	740	601	301	261	1888	1230	435	497	887
STRUCURE	651	15	26	63	369	405	343	209	125	592	372	147	266 5/	381
TT&C	114	7	8	10 3/	49	56	73	30	35	94	58	31	42	65
P&O (DRY)	172	9	16	35	122	142	280	67	58	303	192	97	130	173
BUS (DRY, W/O AKM)	937	31	50	108	540	603	696	306	218	989	622	275	438	619
AKM CASE	-	10	27	38	124	127	-	63	63	-	136	64	105	-
BUS (DRY)	937	41	77	146	664	730	696	369	281	989	758	339	543	619
STA. KEEP. FUEL			14		239			41		86	49		-	
VEL. CORR. FUEL			7		35			143		21	139		37	
P&O FUEL	144	11	21	48	274	348	120	184	104	107	188	216	37	403
BUS (INITIAL IN-ORBIT)			91		903			410		1075	807		543	
BUS (WET)	1081	52	98	194	938	1078	816	553	385	1096	946	555	580	1022
SPACECRAFT (DRY, W/O AKM)	1410	66	143	247	1167	1343	1297	607	479	2877	1852	710	935	1506
SPACECRAFT (DRY)	1410	76	170	285	1291	1470	1297	670	452	2877	1988	744	1040	1506
SPACECRAFT (INITIAL IN-ORBIT)			184		1530			711		2963	2037		1077	
SPACECRAFT (WET)	1554	87	191	333	1565	1818	1417	854	646	2984	2176	990	1077	1909
APOGEE EXPEND.			166	309	1514			582	565	-	1881	894	1465	2052
SPACECRAFT (SEPARATION)			357	642	3079			1436	1211	2984	4057	1884	2542	3961
ADAPTER			-	-	41				54	106	43	78	-	47
OTHER			-	-					-	-		-	3318 6/	
LAUNCH WEIGHT		150	357	642	3120	3340			1265	3090		1962	5860	4008

1/ Includes experiments, sensors, etc., as well as communications.

2/ Includes wiring harness.

3/ TT&C part of communications. Estimated TT&C weight based on INTELSATS I and II.

4/ Excludes 30 lbs. margin allowance.

5/ 60 lbs. Stage III structure remains attached - included in structure weight

6/ Includes 2565 lb. Stage II, 578 lb. heat shield and 175 lb. Stage II to Stage III adaptors.

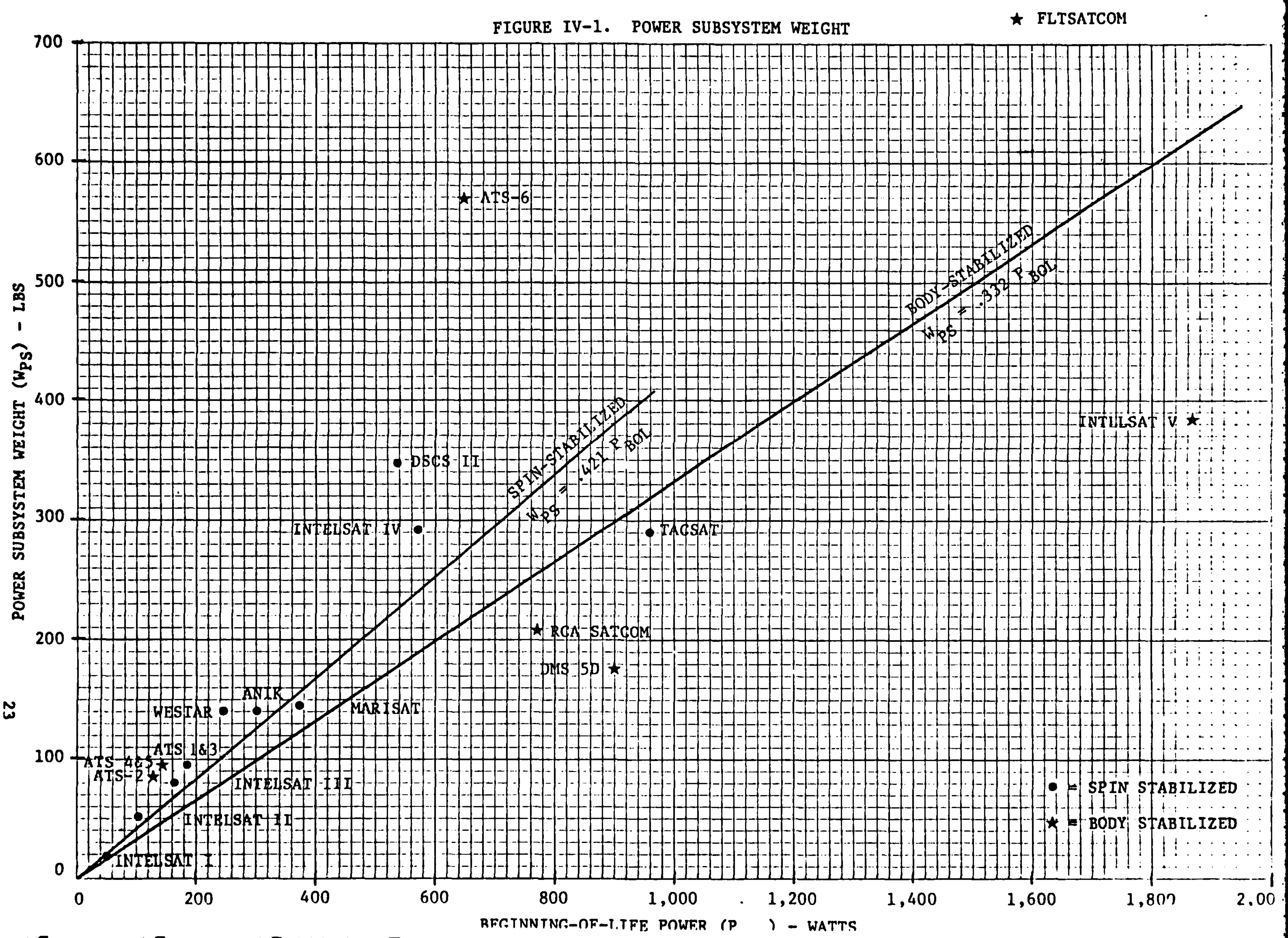
7/ Excludes 165 lbs. margin allowance.

TABLE IV-2

POWER SUBSYSTEM WEIGHTS

SATELLITE	W_{PS} POWER SUBSYSTEM WT. (LBS)	P_{EOL} END-OF-LIFE ARRAY PWR (WATTS)	P_{BOL} BEGINNING-OF-LIFE PWR (WATTS)	Y DESIGN LIFE (YEARS)	P_{BOL}/P_{EOL} FACTOR	CALCULATED P_{BOL}
<u>SPIN-STABILIZED</u>						
TACSAT	290	780	960			
INTELSAT I	17		46			
INTELSAT II	51		100			
INTELSAT III	80	131	161			
INTELSAT IV	291	460	569			
DSCS II	347	357	535			
MARISAT	144	305		5	1.22	372
WESTAR	140	216	241			
ATS-1&3	96	170	180			
ANIK	140	230	300			
<u>BODY-STABILIZED</u>						
ATS-6	569	450	645			
FLTSATCOM	740	1210	1574			
RCA SATCOM	208	550	770			
DMS 5D	177		900			
INTELSAT V	384	1320		7	1.41	1865
ATS-2	86	110	125			
ATS-4&5	96	112	140			

FIGURE IV-1. POWER SUBSYSTEM WEIGHT



SPIN-STABILIZED SPACECRAFT

$$W_{PS} = 38 + .352\ P_{BOL}$$

where,

$$W_{PS} = \text{Power Subsystem Weight - lbs}$$

$$P_{BOL} = \text{Beginning-of-life Power - watts}$$

and

$$SE_{EST} = \pm 59$$

$$\text{Sample Size (N)} = 10$$

$$R^2 = .72$$

While through the origin,

$$W_{PS} = .421\ P_{BOL} \tag{7}$$

and

$$SE_{EST} = \pm 61$$

BODY-STABILIZED SPACECRAFT

$$W_{PS} = 111 + .246\ P_{BOL}$$

where,

$$SE_{EST} = 210$$

$$N = 7$$

$$R^2 = .30$$

while alternatively,

$$W_{PS} = .332\ P_{BOL}$$

and

$$SE_{EST} = \pm 204$$

The data for body-stabilized spacecraft are widely scattered and consequently the regression statistics are poor. There may be definitional problems with the ATS-6 since it obviously falls far outside the norm. There is a trend toward lighter power systems in newer satellites that explains some of the spread. The relationship appears to be a compromise between older, heavier power systems and newer, lighter ones. It probably overestimates power subsystem weights for future spacecraft, while underestimating weights of older systems.

It would be desirable to develop a relationship for power supply weight that took the technological age of the satellite into account. Several attempts were made before the following approach was developed. The technological age of the spacecraft was defined as the year the contract was let for the development, less the year (1958) of the first satellite. Thus a satellite placed under contract for development in 1978 has a technological age of 20 years. The number of pounds of power supply per watt of power obtained was chosen as the appropriate parameter to plot against technological age. Table IV-3 presents these parameters for the spacecraft in the data base.

The data was plotted in Figure IV-2 along with curves resulting from a linear and logarithmic regression. The regression statistics for the body-stabilized spacecraft are as follows:

<u>EXPONENTIAL FIT</u>

$$W_{PS}/P_{BOL} = 3.162\ T^{-.822} \qquad (8)$$

where,

T = Technological Age of Spacecraft

and,

SE_{EST} = .528 (log)

N = 7

R^2 = .28

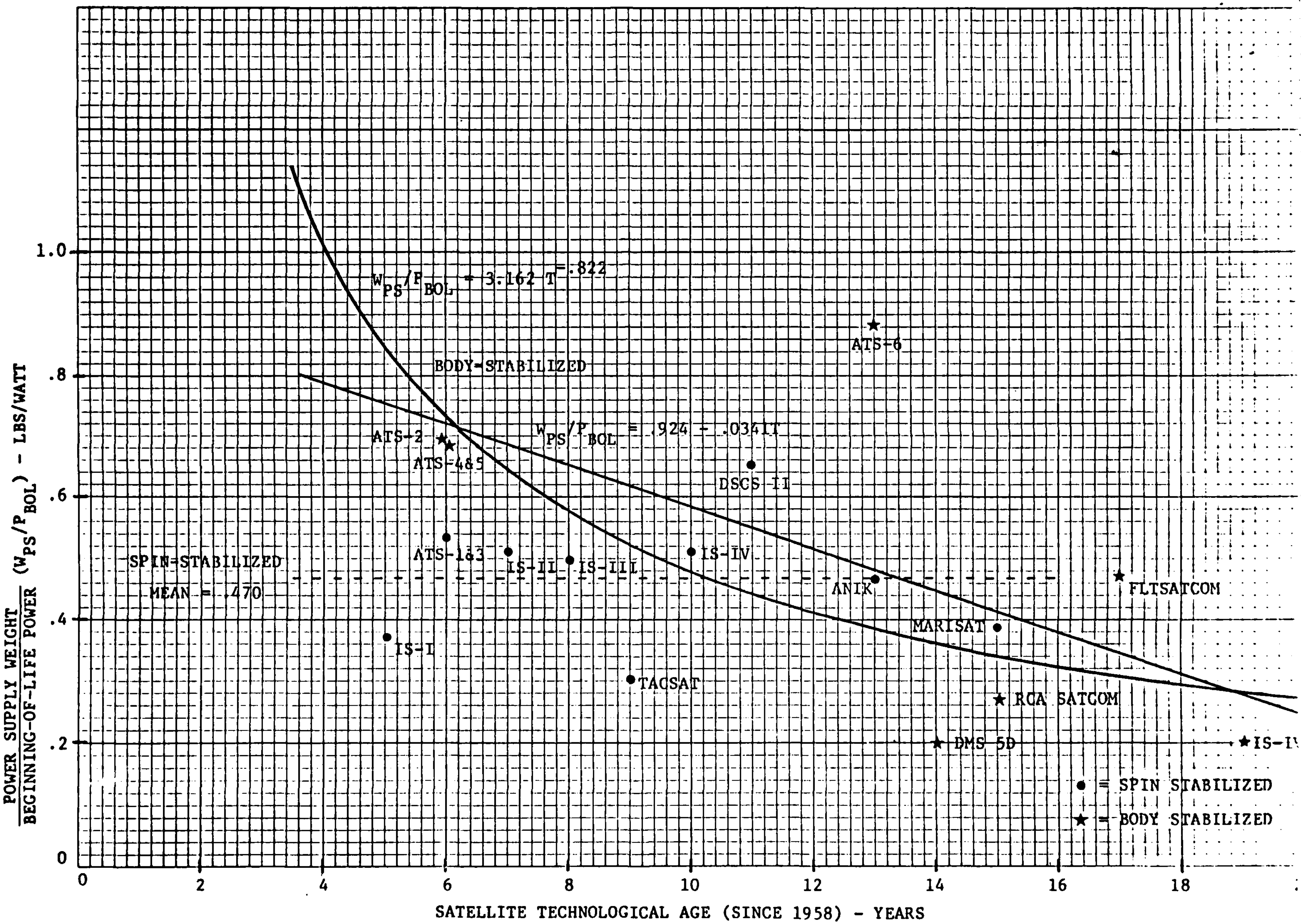
TABLE IV-3

POWER SUPPLY WEIGHT VS. TECHNOLOGY YEAR

SPACECRAFT	W_{PS} POWER SUBSYSTEM WT. (LBS)	BEGINNING-OF-LIFE (WATTS)	W_{PS}/P_{BOL} (LBS/WATTS)	T SATELLITE TECHNOLOGY (YEAR) 1/
SPIN-STABILIZED				
TACSAT	290	960	.302	9
INTELSAT I	17	46	.370	5
INTELSAT II	51	100	.510	7
INTELSAT III	80	161	.497	8
INTELSAT IV	291	569	.511	10
DSCS II	347	535	.649	11
MARISAT	144	372	.387	15
ATS 1&3	96	180	.533	6
ANIK	140	300	.467	13
BODY-STABLIZED				
ATS-6	569	645	.882	13
FLTSATCOM	740	1574	.470	17
RCA SATCOM	208	770	.270	15
DMS 5D	177	900	.197	14
INTELSAT V	384	1865	.206	19
ATS-2	86	125	.688	6
ATS-4&5	96	140	.686	6

1/ Based on years since 1958 to contract start date.

JRE 2. POWER SUPPLY WEIGHT / BEGINNING-OF-LIFE POWER



LINEAR FIT

$$W_{PS}/P_{BOL} = .924 - .0341\ T$$

where,

$SE_{EST} = .231$

$N = 7$

$R^2 = .28$

Upon examination of the graph, Figure IV-2 is more convincing than the above statistics. Again, ATS-6 is a distinct outlyer. The decrease in pounds/watt is rather obvious in the graph and the relationships seem reasonable, though not very precise. The exponential relationship is preferred, as it is more conservative in the later years -- which is of paramount importance to the model.

A similar attempt with spin-stabilized spacecraft produced no significant relationship. The previously derived relationship (7) plotted in Figure IV-1 is therefore used for this type spacecraft.

B. Spacecraft Bus

Once the satellite payload weight has been established, the next step is to determine the weight of the spacecraft bus necessary to carry and sustain the payload in orbit. The bus consists of the structure (including thermal control), TT&C and the Positioning & Orientation (P&O) system. If used, the Apogee Kick Motor (AKM) case becomes part of the orbital system and will have some effect on the size of the structure and the P&O system. Fortunately, the AKM case is relatively small compared to the bus and its effect on other components is small. (This was tested using regressions which included the AKM weight, but they are not described here). The P&O fuel weight will also have some effect on the structure and P&O system required to hold and move it, but it becomes very difficult to isolate the effects. (Regressions run on bus weight with P&O fuel included achieved poorer results for body-stabilized spacecraft, but slightly better for spin-stabilized). After considerable trial and error the most straight forward approach seemed best. Both AKM case and P&O Fuel are not considered part of the basic bus, but can be added if, and as, required.

The spacecraft bus weight (dry) and payload weight from Table IV-1 are plotted in Figure IV-3. Regressions run on the data yield the following:

SPIN-STABILIZED

$$W_{BX} = 8.5 + 1.044\ W_{PY}$$

where,

W_{BX} = Bus weight, dry, w/o AKM - lbs.

W_{PY} = Payload weight - lbs.

and,

SE_{EST} = 188.6

N = 9

R^2 = .65

BODY-STABILIZED

$$W_{BX} = 164.2 + .430\ W_{PY} \qquad (9)$$

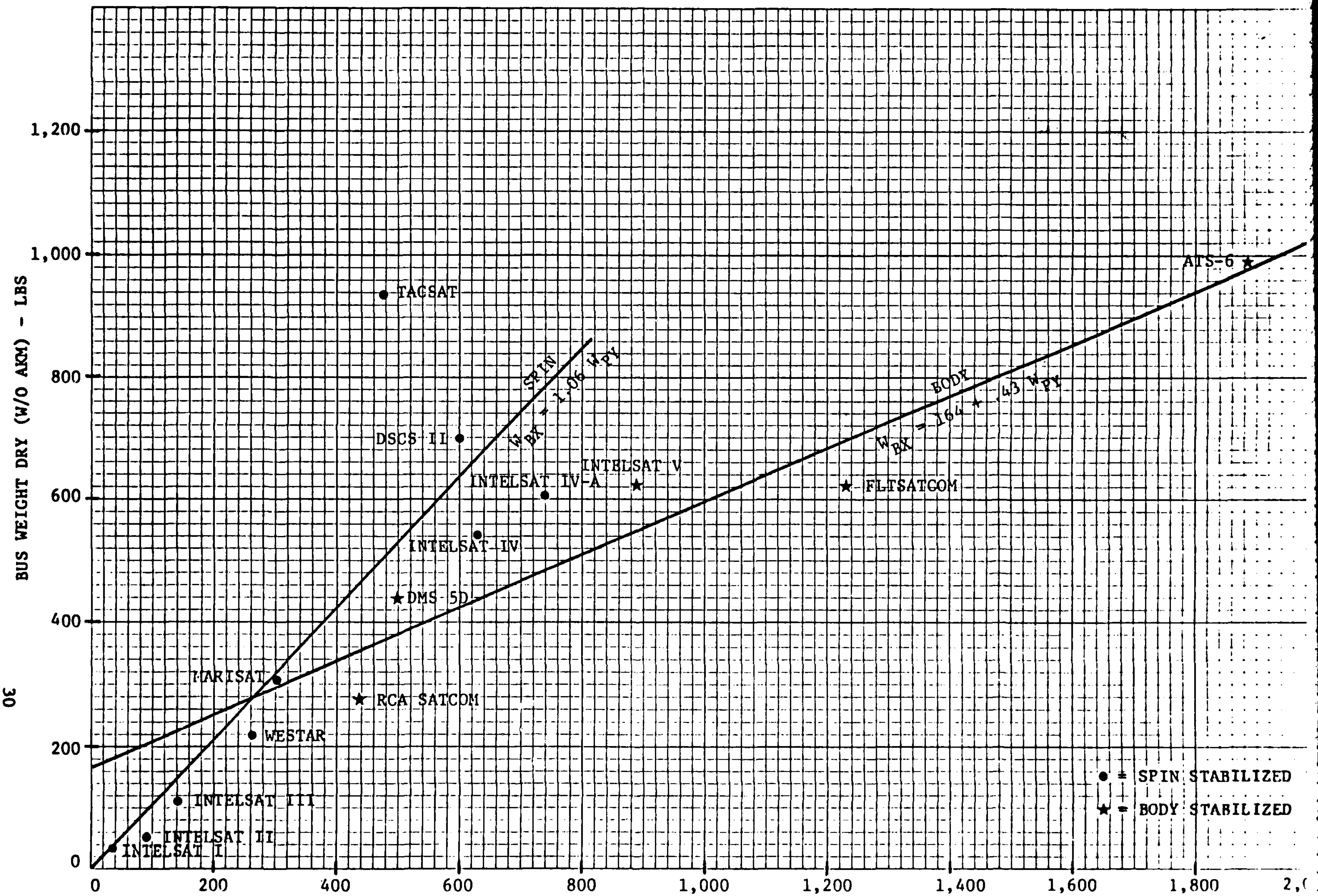
where,

SE_{EST} = 81.7

N = 5

R^2 = .91

FIGURE IV-3. BUS WEIGHT



The intercept is very small and not significant for the spin-stabilized spacecraft. Rerunning the regression yields:

$$W_{BX} = 1.060\ W_{PY} \tag{10}$$

where,

$SE_{EST} = 146.7$

C. Components of Bus

In establishing weight relationships for Structure, TT&C and P&O (Dry) as a function of the Spacecraft Bus weight, it is important to account for 100% of the bus weight. By using a common data base, there should be no problem in this area. There was further concern that the relationships would balance out, with large negative constants cancelling positive constants. There was no need for this concern as all constants were very small. All but two were rated statistically not significant and the other two were toss ups. All regressions were rerun to remove the constant terms and the results are most satisfactory.

1. Structure. Figure IV-4 shows plots of the structure data of Table IV-1. The regression results are:

SPIN-STABILIZED

$$W_{ST} = -8.2 + .654\ W_{BX}$$

where,

W_{ST} = Structure Weight - lbs.

W_{BX} = Bus (dry, w/o AKM) weight - lbs.

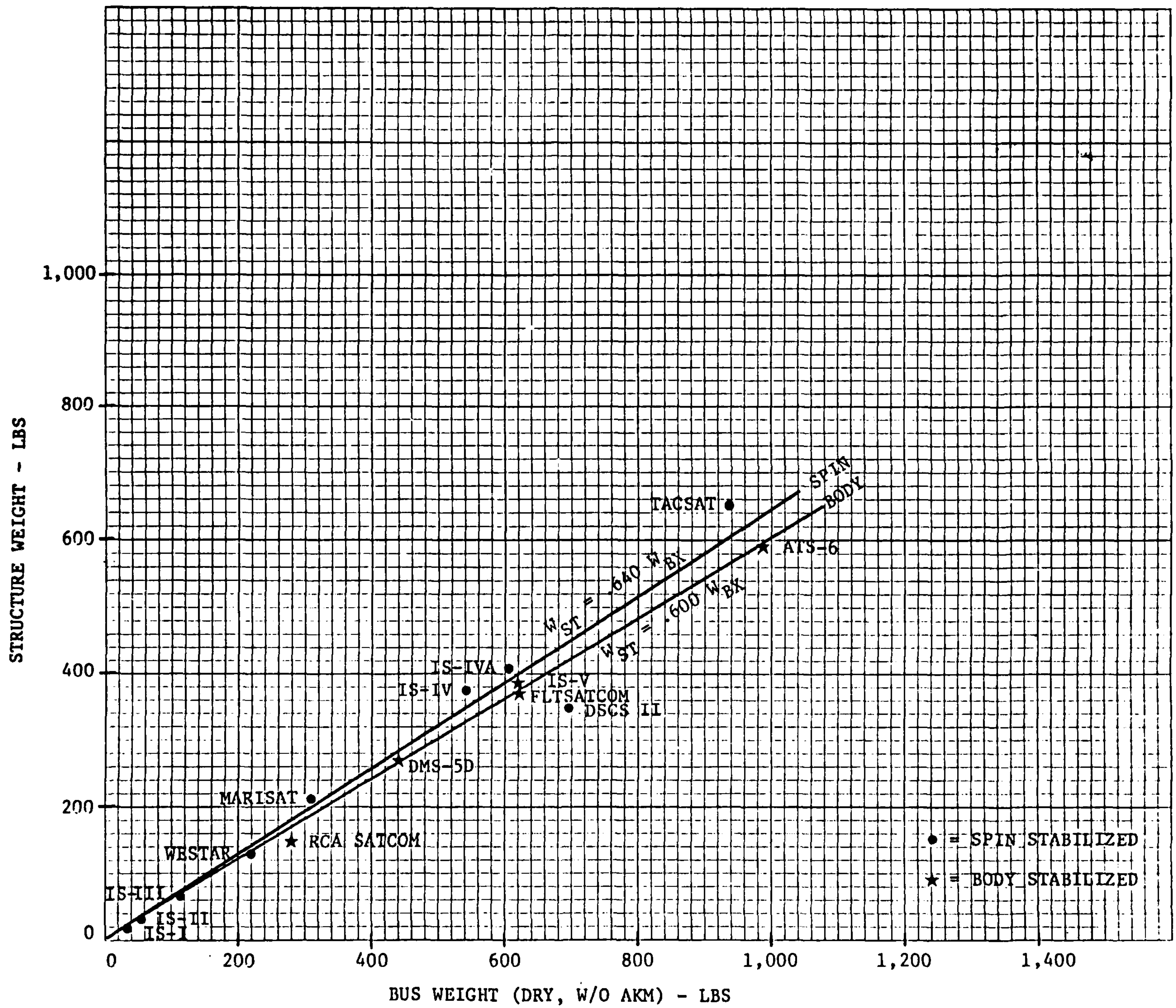
and,

$SE_{EST} = 45.2$

$N = 9$

$R^2 = .96$

FIGURE IV-4. STRUCTURE WEIGHT



and with constant removed,

$$W_{ST} = .640\ W_{BX} \tag{11}$$

where,

$SE_{EST} = 42.6$

<u>BODY-STABILIZED</u>

$$W_{ST} = -11.6 + .617\ W_{BX}$$

where,

$SE_{EST} = 10.6$
$N = 5$
$R^2 = .99$

and with constant removed,

$$W_{ST} = .600\ W_{BX} \tag{12}$$

where,

$S_{EST} = 10.4$

2. <u>TT&C</u>. TT&C weights are plotted in Figure IV-5. Results of the regressions are:

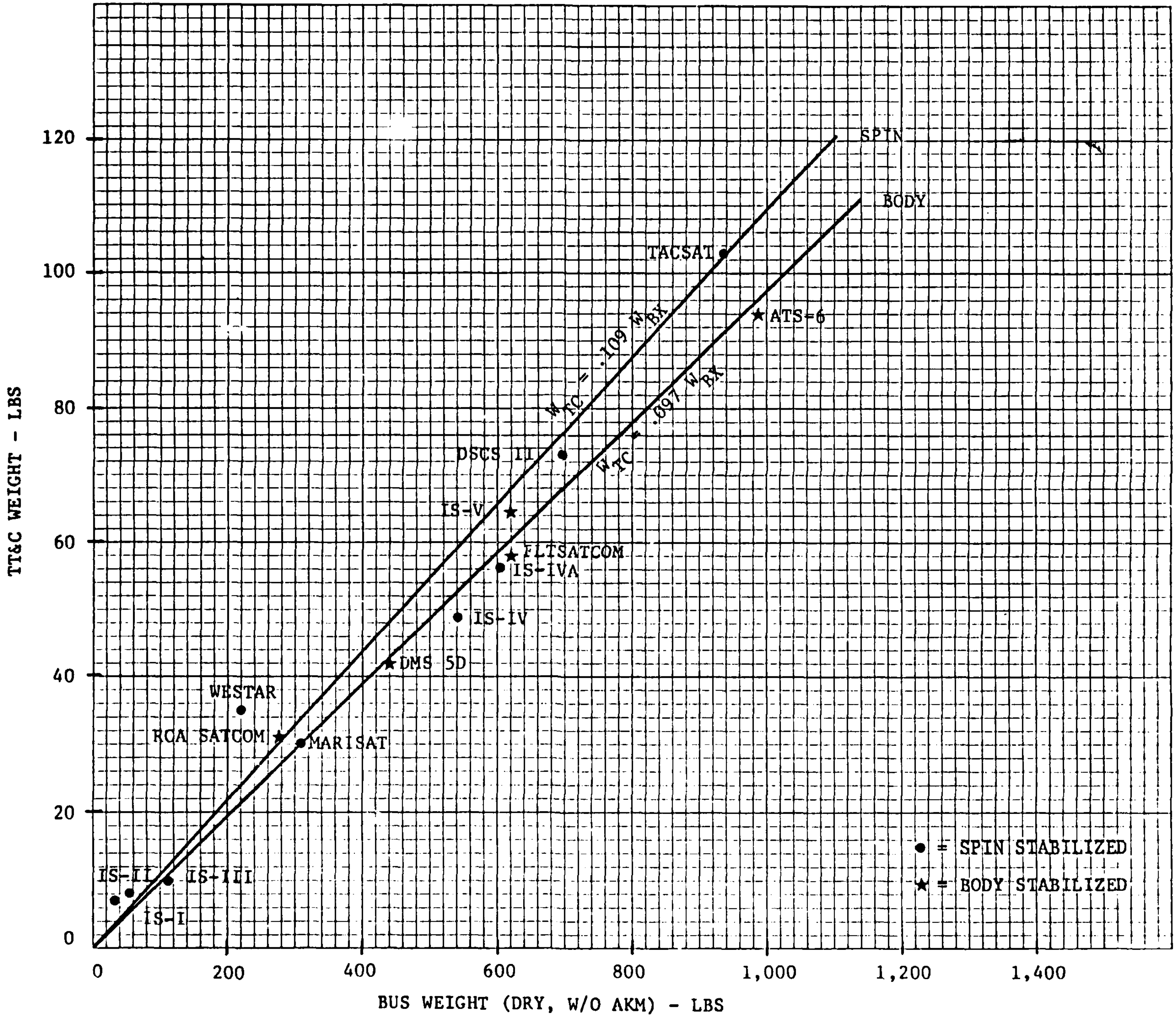
<u>SPIN-STABILIZED</u>

$$W_{TC} = .8 + .107\ W_{BX}$$

where,

W_{TC} = TT&C weight - lbs.

FIGURE IV-5. TT&C WEIGHT



and,

$$SE_{EST} = 8.4$$
$$N = 9$$
$$R^2 = .94$$

and with constant removed,

$$W_{TC} = .109\ W_{BX} \qquad (13)$$

where,

$$SE_{EST} = 7.9$$

BODY-STABILIZED

$$W_{TC} = 5.0 + .090\ W_{BX}$$

where,

$$SE_{EST} = 3.4$$
$$N = 5$$
$$R^2 = .98$$

and with constant removed,

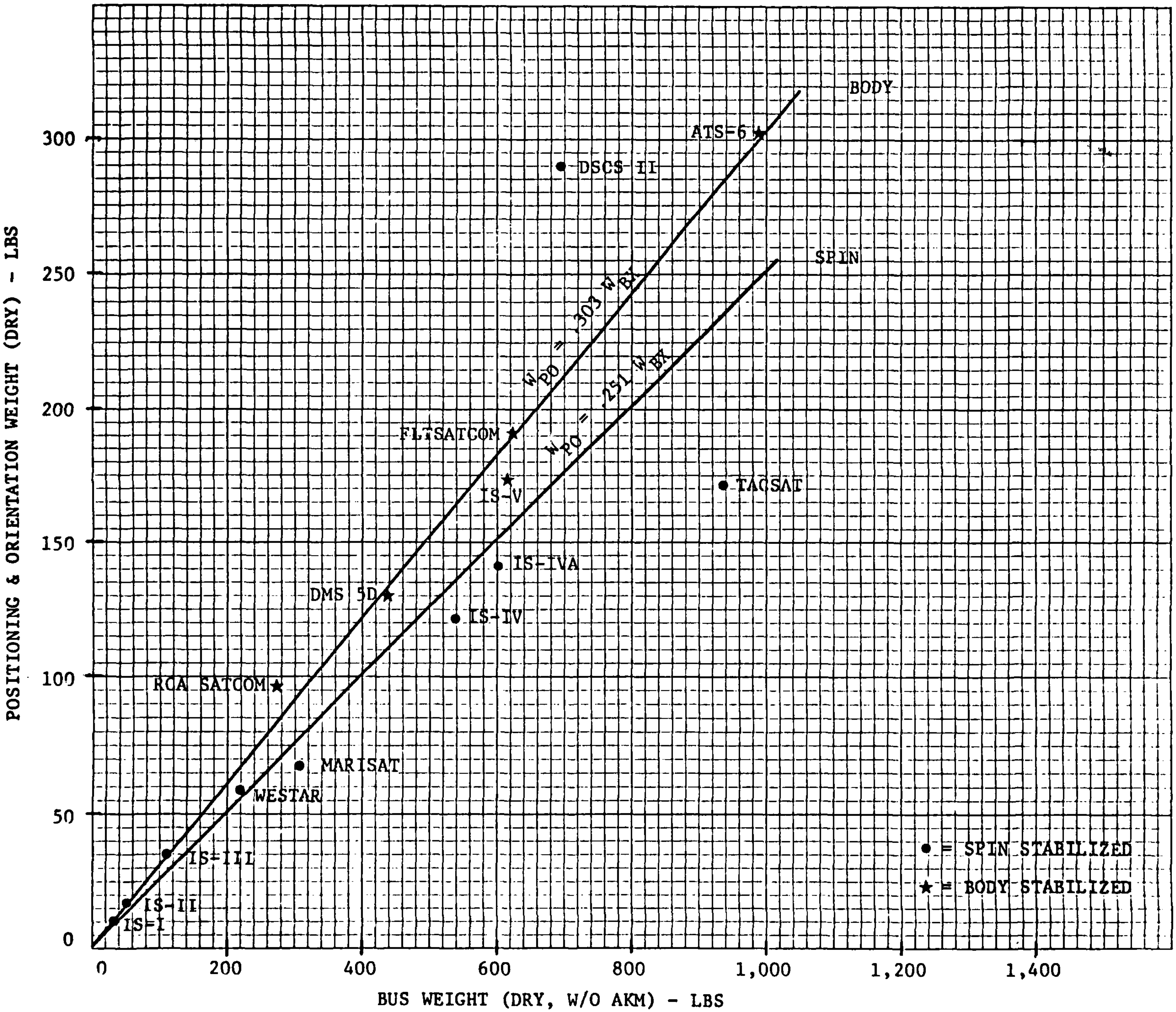
$$W_{TC} = .097\ W_{BX} \qquad (14)$$

where,

$$SE_{EST} = 3.6$$

3. P&O (Dry). The P&O system, including the Propulsion system as well as the Attitude Control and Determination system, makes up the remainder of the Spacecraft Bus. Weights of the P&O system are plotted in Figure IV-6, as well as regression curves.

FIGURE IV-6. P&O WEIGHT (DRY)



SPIN-STABILIZED

$$W_{PO} = 7.5 + .239\ W_{BX}$$

where,

W_{PO} = Position & Orientation (dry) weight - lbs.

and,

$SE_{EST} = 46.8$

$N = 9$

$R^2 = .72$

while with zero intercept,

$$W_{PO} = .251\ W_{BX} \qquad (15)$$

and,

$SE_{EST} = 44.1$

BODY-STABILIZED

$$W_{PO} = 6.6 + .293\ W_{BX}$$

where,

$SE_{EST} = 11.5$

$N = 5$

$R^2 = .98$

while without constant,

$$W_{PO} = .303\ W_{BX} \qquad (16)$$

and,

$SE_{EST} = 10.4$

D. Apogee Kick Motor Case

Not all spacecraft employ an Apogee Kick Motor, so the AKM case weight is not always required in the model. In general, synchronous orbit spacecraft utilize an AKM. They may employ a precision upper stage or separable motor, instead, that does not add to on-orbit weight. As a result, some indication of launch method to be employed is necessary to determine if the AKM case weight should be added in. It is relatively small, so affect on total satellite weight is correspondingly small.

AKM case weights are plotted in Figure IV-7. The type of spacecraft stabilization should have no affect on the AKM case weight - only the total bus weight. The regression statistics as well as the plotted data confirm this.

$$W_{AM} = 12.3 + .199\ W_{BX} \tag{17}$$

where,

W_{AM} = Apogee Kick Motor case weight - lbs.

and,

$SE_{EST} = 6.7$

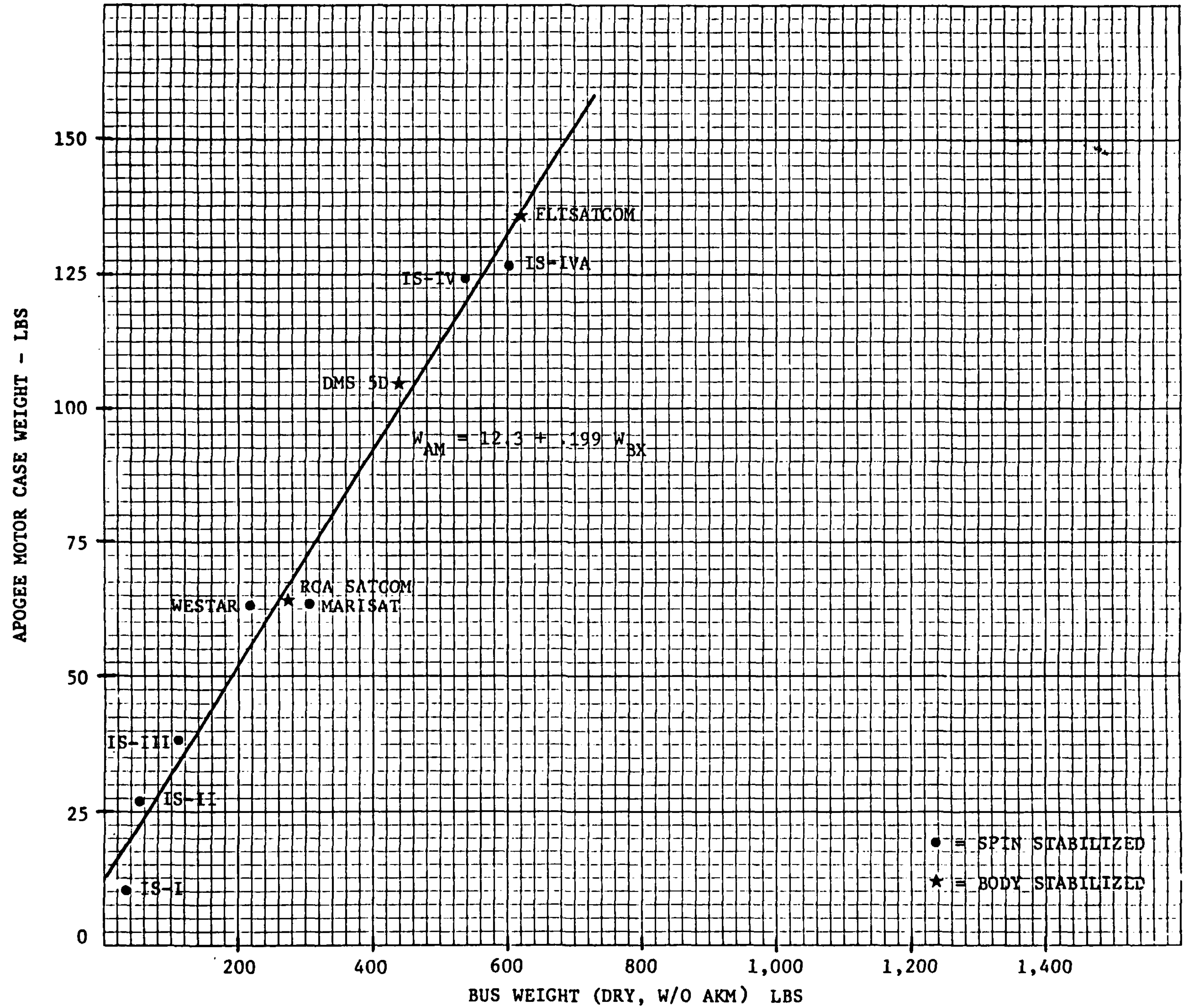
$N = 10$

$R^2 = .98$

E. Position & Orientation Fuel

The P&O fuel is made up of velocity correction fuel used during initial orbit injection and station-keeping fuel to maintain position once in orbit. For synchronous orbit spacecraft, the station-keeping fuel generally predominates. This is because the AKM or precision upper stage generally takes care of most of the velocity correction for orbit injection. There are, of course, exceptions. In less-than-synchronous orbit spacecraft, the opposite situation is likely to occur. More P&O

FIGURE IV-7. APOGEE MOTOR CASE



fuel is used, and the largest part is used to inject into orbit. This may obviate need for another stage or separable motor altogether. In addition, early satellites (primarily spin-stabilized) generally used fuel for orientation on-orbit whereas the newest (primarily body-stabilized) spacecraft generally employ momentum wheels. As a result, predicting P&O fuel without detailed knowledge of the launch sequence and positioning system is poor at best. This information is very likely unknown to the model user in the early stages. The relationships derived here from historical data should obviously be used with considerable reservation. Unless refined by other inputs, they represent only a crude approximation of what the situation may be in an actual spacecraft.

Data on P&O fuel for the data base spacecraft are given in Table IV-4 and are plotted in Figure IV-8 against Spacecraft Dry Weight x Design Life. Many attempts were made to arrive at a reasonable relationship without much success before this approach was established. (Attempts to split P&O fuel into velocity correction fuel and station-keeping fuel were unsuccessful because of insufficient data). P&O fuel (at least the station-keeping portion) should be directly proportional to design life. The plot of Figure IV-8 bears this out. Regressions were run and in both cases the intercepts proved to be not significant statistically, so the regressions were rerun with zero intercepts.

SPIN-STABILIZED

$$W_{PF} = 7.6 + .0299 \, (W_{SD} \cdot Y)$$

where,

W_{PF} = P&O fuel weight - lbs.

W_{SD} = Spacecraft dry weight - lbs.

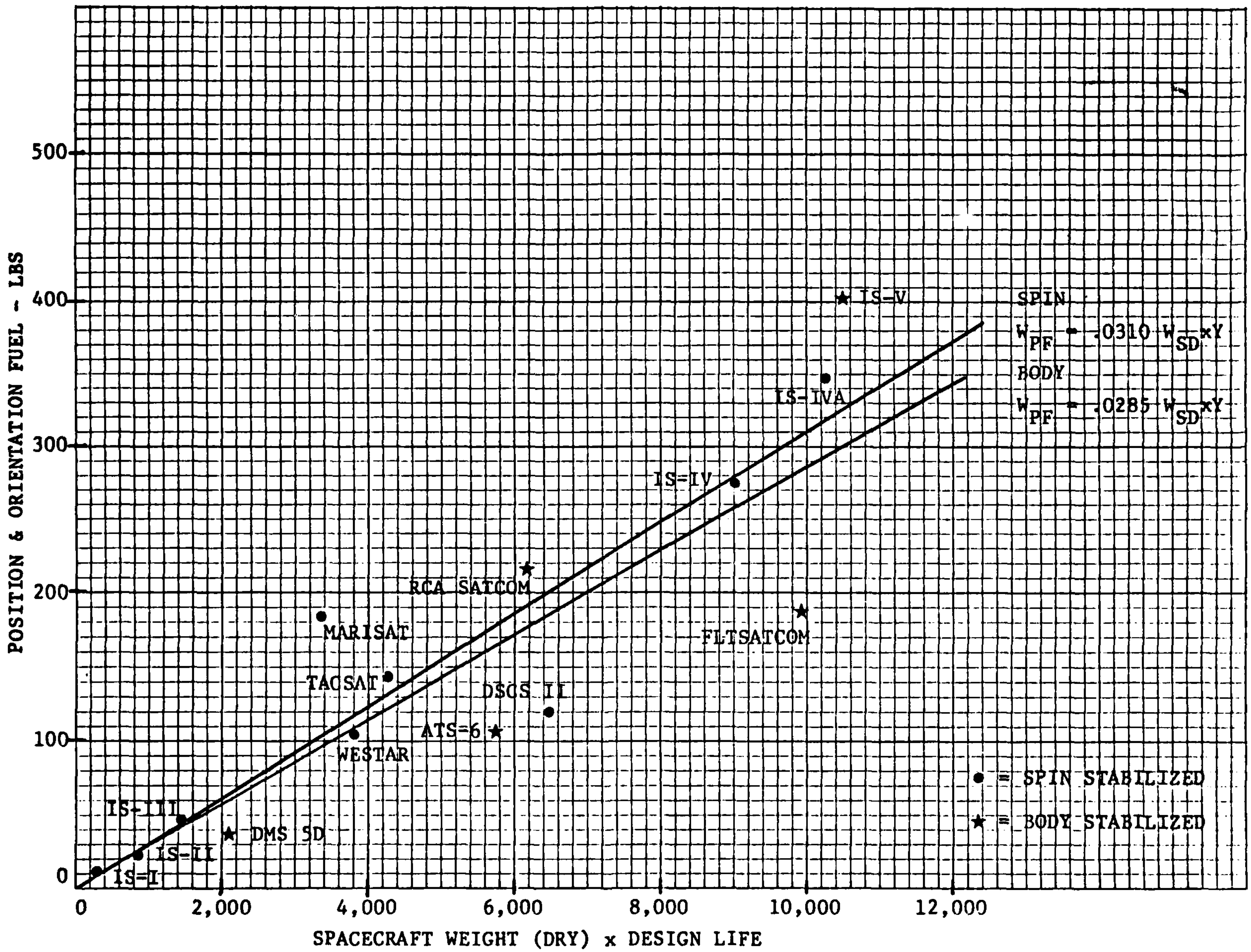
Y = Design Life - years

TABLE IV-4

SPACECRAFT POSITIONING & ORIENTATION FUEL REQUIREMENTS

SPACECRAFT	P&O FUEL (LBS)	SPACECRAFT (DRY) WEIGHT (LBS)	DESIGN LIFE (YRS)	SPACECRAFT WEIGHT x DESIGN LIFE
SPIN-STABILIZED				
TACSAT	144	1410	3	4230
INTELSAT I	11	76	3	228
INTELSAT II	21	170	3	850
INTELSAT III	48	285	5	1425
INTELSAT IV	274	1291	7	9037
INTELSAT IVA	348	1470	7	10290
DSCS II	120	1297	5	6485
MARISAT	184	670	5	3350
WESTAR	104	542	7	3794
BODY-STABILIZED				
ATS-6	107	2877	2	5754
FLTSATCOM	188	1988	5	9940
RCA SATCOM	216	774	8	6192
DMS 5D	37	1040	2	2080
INTELSAT V	403	1506	7	10542

FIGURE IV-8. POSITION & ORIENTATION FUEL



and,

$$SE_{EST} = 44.9$$
$$N = 9$$
$$R^2 = .85$$

while with zero intercept,

$$W_{PF} = .0310\ W_{SD} \cdot Y \tag{18}$$

and,

$$SE_{EST} = 42.2$$

BODY-STABILIZED

$$W_{PF} = -39.7 + .033\ (W_{SD} \cdot Y)$$

where,

$$SE_{EST} = 88.7$$
$$N = 5$$
$$R^2 = .59$$

and with zero intercept,

$$W_P = .0285\ W_{SD} \cdot Y \tag{19}$$

where,

$$SE_{EST} = 78.9$$

F. Apogee Fuel

Spacecraft utilizing Apogee Kick Motors for injection into synchronous orbit require fuel which should be directly proportional to satellite weight. In this case, the P&O Fuel is included since it requires lifting into, or near, synchronous orbit. As seen from the graph of Figure IV-9, the relationship is straight-forward.

$$W_{AF} = -10.2 + .977\ W_{SN}$$

where,

W_{AF} = Apogee Fuel weight - lbs.

W_{SW} = Spacecraft weight, incl. fuel - lbs.

and,

$SE_{EST} = 220$

$N = 9$

$R^2 = .90$

while with adjusted constant,

$$W_{AF} = .970\ W_{SW} \qquad (20)$$

where,

$SE_{EST} = 206$

G. Spacecraft to Upper Stage Adapter

The weights of the adapters, where available, were plotted against spacecraft weight at separation in Figure IV-10. The weight of the AKM and its fuel is included in this spacecraft weight parameter as it must all be supported by the adapter. The results of the regression attempt

FIGURE IV-9. APOGEE FUEL

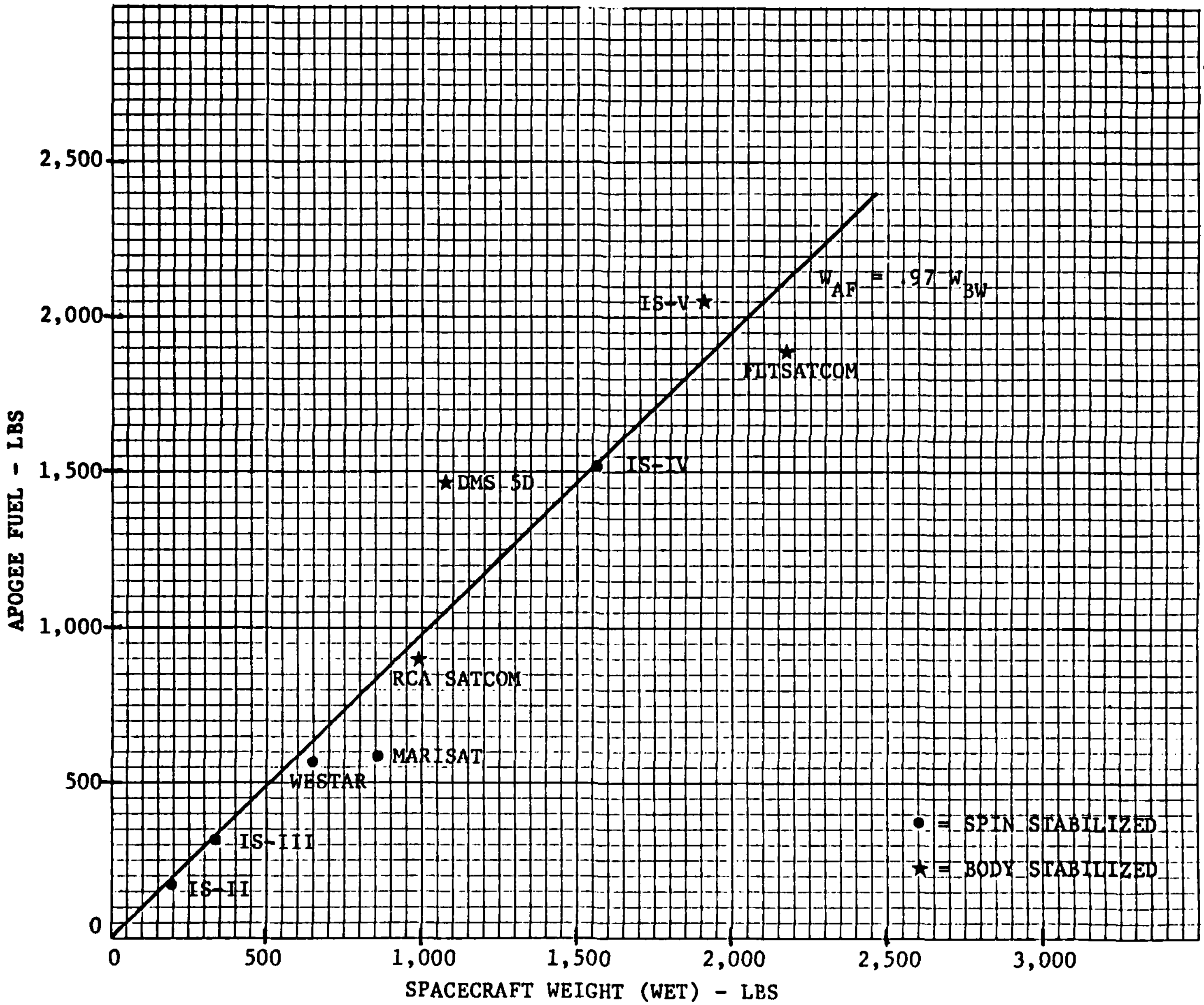
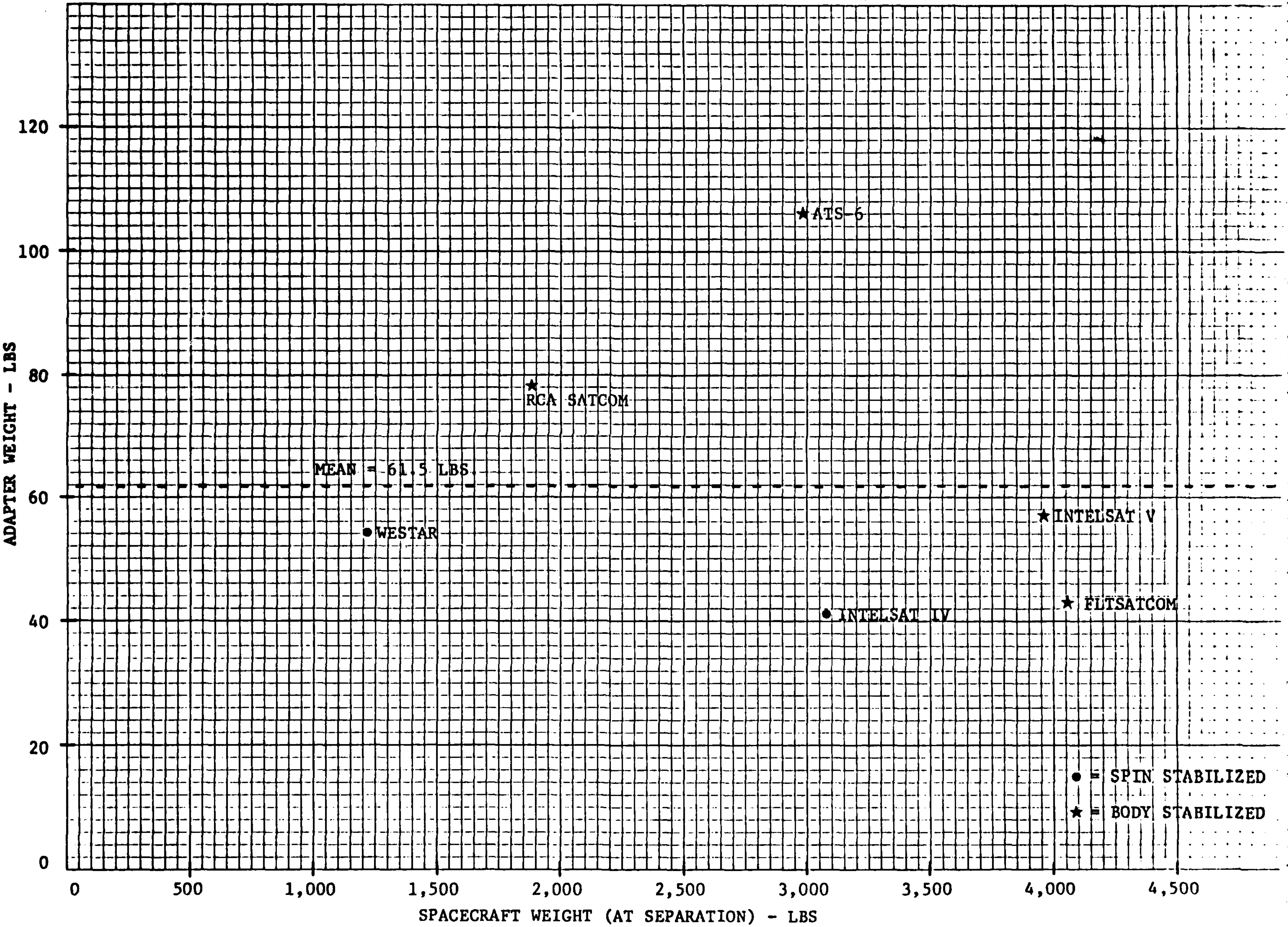


FIGURE IV-10. ADAPTER (SPACECRAFT - UPPER STAGE)



indicated there was no correlation. The adapters varied in weight from 40 to 106 pounds, so the mean was chosen as the appropriate relation:

$$W_{AA} = 61.5 \tag{21}$$

where,

W_{AA} = Spacecraft to Upper Stage Adapter weight - lbs.

V. UPPER STAGE REQUIREMENTS

Space shuttle launches during the 1980 time period will place the satellites into a 160 nautical mile parking orbit. The maximum load is 65,000 lbs. into an orbit inclined 28.5 degress (due east launch from Kennedy Space Center -- the only launch orbit of interest for synchronous orbit satellites). The maximum length of the cargo bay is 60 feet. An upper stage is then required to inject the satellite into a synchronous transfer orbit from which the apogee motor will be fired to circularize the orbit. As an alternative, an upper stage of greater size and greater control precision can be used to inject the satellite directly into synchronous orbit. In this case no apogee motor would be required.

There are only two basic vehicles contemplated for development for use with the shuttle. The Spinning Solid Upper Stage (SSUS) comes in two versions, a Delta class and an Atlas-Centaur class, named for the expendable launch vehicles they generally replace. The second is the Interim Upper Stage (IUS) being developed by the Air Force that would directly inject payloads into synchronous orbit. Each of these upper stages requires a cradle to hold it within the shuttle bay. For the SSUS's, a spin platform is required to spin up the spacecraft prior to ejection and upper stage firing.

Not only will the size of the synchronous-orbit spacecraft affect the size and cost of the upper stage vehicle required, the shuttle launch charges will be proportional to the total weight or length of the spacecraft, cradle and spin platform in relation to shuttle capability (whichever is greater). It might be less costly, in borderline cases, to opt for the lighter spacecraft requiring a lighter and shorter upper stage.

Information on the upper stages is tentative at the present time. Table III-3 summarizes the current best estimates available on size, weight and capacity of the three upper stage options.

VI. APPLICATION OF MODEL

A. Procedure

A sample worksheet for use of the mass and power model appears in Figure VI-1. Line numbers on the worksheet correspond to the number of the applicable relationship summarized in Table II-2. A typical modelling exercise might be performed in the following manner:

1. Fill in Worksheet Headings.
   a. Spin-stabilized and body-stabilized spacecraft use different relationships, so this must be specified. If not known, separate models may be constructed for each type.
   b. Development contract year is required to compute Technological Age, T.
   c. Launch orbit determines whether an AKM is required. Synchronous transfer orbit generally requires one, direct injection does not. Non-synchronous orbits generally do not, but a separable rocket motor may be used.
2. Fill in Actual Data. It is suggested that all known data be filled in the first column -- to compare results when modelling is completed.
3. Select Model Inputs. Enter inputs in the second column. Circling the inputs helps to identify them later.
   a. Enter communications subsystem weight on line 1.
   b. Normally, communications subsystem power would be input on line 21. However, if end-of-life power has been estimated, this may be entered on line 22 instead. Doing so would give preference to judgement of data source rather than the model.
4. Complete Model. Compute entries to line numbers using relationships of Table II-2.
   a. Select appropriate relationships based on whether spacecraft is spin-stabilized or body-stabilized.
   b. Compute power first, then weights.

FIGURE VI-1

SAMPLE SATELLITE WEIGHT & POWER ESTIMATE WORKSHEET

Spacecraft	Stabilization	Design Life	Devel.Contr.Yr.	Launch Orbit

◯ = indicates input to model

WEIGHT	SYMBOL	WT.-LBS	WT-LBS
1. COMMUNICATIONS	W_C		
2. POWER SUPPLY	W_{PS}		
3. SPACECRAFT PAYLOAD	W_{PY}		
6. STRUCTURE	W_{ST}		
7. TT&C	W_{TC}		
8. POSITION & ORIENT (DRY)	W_{PO}		
9. APOGEE MOTOR CASE	W_{AM}		
12. P&O FUEL	W_{PF}		
4. BUS (DRY, W/O AKM)	W_{BX}		
10. BUS (DRY)	W_{BD}		
13. BUS (WET)	W_{BW}		
11. SPACECRAFT (DRY)	W_{SD}		
14. SPACECRAFT (WET)	W_{SW}		
15. APOGEE FUEL	W_{AF}		
16. SPACECRAFT (SEPARATION)	W_{SS}		
17. ADAPTER	W_{AA}		
18. UPPER STAGE	W_{US}		
19. CRADLE/ADAPTER	W_{CR}		
20. SHUTTLE LOAD	W_L		

POWER	SYMBOL	PWR.-W.	PWR-W.
1. COMMUNICATIONS	P_C		
3. POWER SUPPLY	P_{PS}		
4. SATELLITE PAYLOAD	P_{PY}		
5. BUS	P_B		
2. END-OF-LIFE	P_{EOL}		
6. BEGINNING-OF-LIFE	P_{BOL}		

c. Technological age, T, is obtained by subtracting 1958 from year development was contracted.

d. The AKM case weight should be added only for synchronous-transfer orbit. In such cases, a separable rocket motor is comparable, except that the case does not remain attached in orbit. All other launch orbits should be assumed to have no AKM.

e. Reference to Table II-3 is necessary to estimate weight, and size, of suitable upper stage and cradle/adapter for shuttle launch.

B. Test Samples

Two samples of completed worksheets are given in Figures VI-2 and VI-3. A body-stabilized spacecraft (FLTSATCOM) and a spin-stabilized spacecraft (MARISAT) were chosen to illustrate results obtained from the model. Percent differences between modelled values and actual values were computed as a test of how well the model performed. Some of the individual components, especially propulsion or apogee fuels, show considerable variation. The overall results, however, are very satisfactory.

FIGURE VI-2

SATELLITE WEIGHT & POWER ESTIMATE

FLTSATCOM Spacecraft	3-Axis Stabilization	5 Design Life	1975 Devel. Contr. Yr.	Synch, Transfer Launch Orbit

◯ = input

WEIGHT	SYMBOL	ACTUAL WT.-LBS	MODEL WT-LBS	DIFFERENCE %
1. COMMUNICATIONS	W_C	490	490	NA
2. POWER SUPPLY	W_{PS}	740	544	-26
3. SPACECRAFT PAYLOAD	W_{PY}	1,230	1,034	-16
6. STRUCTURE	W_{ST}	372	365	- 2
7. TT&C	W_{TC}	58	61	+ 5
8. POSITION & ORIENT (DRY)	W_{PO}	192	183	- 5
9. APOGEE MOTOR CASE	W_{AM}	136	134	- 1
12. P&O FUEL	W_{PF}	188	258	+37
4. BUS (DRY, W/O AKM)	W_{BX}	622	609	- 2
10. BUS (DRY)	W_{BD}	758	743	- 2
13. BUS (WET)	W_{BW}	946	1,001	+ 6
11. SPACECRAFT (DRY)	W_{SD}	1,988	1,777	-11
14. SPACECRAFT (WET)	W_{SW}	2,176	2,035	- 6
15. APOGEE FUEL	W_{AF}	1,881	1,974	+ 5
16. SPACECRAFT (SEPARATION)	W_{SS}	4,057	4,009	- 1
17. ADAPTER	W_{AA}	43	62	+44
18. UPPER STAGE	W_{US}			
19. CRADLE/ADAPTER	W_{CR}	——	——	——
20. SHUTTLE LOAD	W_L			

POWER	SYMBOL	ACTUAL PWR.-W.	MODEL PWR-W.	DIFFERENCE %
1. COMMUNICATIONS	P_C	1,072	1,072	NA
3. POWER SUPPLY	P_{PS}	56	81	+45
4. SATELLITE PAYLOAD	P_{PY}	1,128	1,153	+ 2
5. BUS	P_B	109	204	+87
2. END-OF-LIFE	P_{EOL}	1,237	1,357	+10
6. BEGINNING-OF-LIFE	P_{BOL}	1,574	1,757	+12

FIGURE VI-3

SATELLITE WEIGHT & POWER ESTIMATE

MARISAT Spacecraft	SPIN Stabilization	5 Design Life	1973 Devel.Contr.Yr.	SYNCH. TRANSFER Launch Orbit

(circle) = input

WEIGHT	SYMBOL	ACTUAL WT.-LBS	MODEL WT-LBS	DIFFERENCE %
1. COMMUNICATIONS	W_C	157	157	NA
2. POWER SUPPLY	W_{PS}	144	144	0
3. SPACECRAFT PAYLOAD	W_{PY}	301	301	0
6. STRUCTURE	W_{ST}	209	204	- 2
7. TT&C	W_{TC}	30	35	+17
8. POSITION & ORIENT (DRY)	W_{PO}	67	80	+19
9. APOGEE MOTOR CASE	W_{AM}	63	76	+21
12. P&O FUEL	W_{PF}	184	108	-41
4. BUS (DRY, W/O AKM)	W_{BX}	306	319	+ 4
10. BUS (DRY)	W_{BD}	369	395	+ 7
13. BUS (WET)	W_{BW}	553	503	- 9
11. SPACECRAFT (DRY)	W_{SD}	670	696	+ 4
14. SPACECRAFT (WET)	W_{SW}	854	804	- 6
15. APOGEE FUEL	W_{AF}	582	780	+34
16. SPACECRAFT (SEPARATION)	W_{SS}	1,436	1,584	+10
17. ADAPTER	W_{AA}		62	
18. UPPER STAGE	W_{US}			
19. CRADLE/ADAPTER	W_{CR}	—	—	—
20. SHUTTLE LOAD	W_L			

POWER	SYMBOL	ACTUAL PWR.-W.	MODEL PWR-W.	DIFFERENCE %
1. COMMUNICATIONS	P_C	223	223	NA
3. POWER SUPPLY	P_{PS}	2	17	+750
4. SATELLITE PAYLOAD	P_{PY}	225	240	+ 7
5. BUS	P_B	73	42	-42
2. END-OF-LIFE	P_{EOL}	305	282	- 8
6. BEGINNING-OF-LIFE	P_{BOL}		344	

REFERENCES

1 *Mass and Power Model for Communications Spacecraft,* G.R. Kreisel, J. Watson Noah Associates, Inc., WN-1064A-USN, January 1977.

2 *SAMSO Unmanned Spacecraft Cost Model,* Third Edition, C.J. Rohwer, et al, August 1975.

3 *A Technique for Modeling Communications Satellite,* J.D. Kiesling, et al, COMSAT Technical Review, Volume 2, Number 1, Spring 1972.

APPENDIX

DEFINITIONS

AKM	Apogee Kick Motor. Rocket motor used to propel synchronous orbit satellites from transfer orbit into final orbit. The case usually remains attached to the spacecraft.
Beginning-of-Life	Refers to power requirement to which spacecraft much be designed. Determination of solar array power output over spacecraft lifetime is taken into account.
Bus	The vehicle that supports the payload. With the exception of a small portion of the spacecraft power, the Bus could stand alone in orbit and might be used to support different payloads.
Dry	Refers to spacecraft or bus weight, excluding weight of positioning and orientation fuel. Includes weight of AKM, if applicable.
Dry, w/o AKM	Refers to spacecraft or bus weight, excluding weight of positioning and orientation fuel and weight of the AKM, if applicable.
End-of-Life	Refers to power requirement at the end of the spacecraft design life, usually the minimum solar array power requirement to keep all subsystems operating.
On-orbit	Refers to spacecraft or bus weight when fully positioned and oriented in intended orbit. Apogee fuel will have been expended. Velocity correction fuel of the P&O system will also have been expended, but the lifetime station-keeping fuel of the P&O system will remain.
Payload	The heart of the satellite consisting of the communications subsystem and the power supply which powers it. Although some power is also required for the bus, this is usually a small percentage of the total.
P&O	Positioning & Orientation system.

DEFINITIONS (Continued)

Separation	Refers to condition or weight of the spacecraft or bus at the time of separation from the upper stage of the launch vehicle. Usually used in booster launches, the term also applies for STS launches where an upper stage is used to boost the spacecraft to higher orbit.
Spacecraft	The satellite consisting of payload, supporting bus and fuels. The weight of the spacecraft varies greatly, depending primarily on amount of on-board fuel.
STS	Space Transportation System, commonly called the space shuttle.
Wet	Refers to spacecraft or bus weight, including full load of positioning and orientation fuel.

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